In-Vehicle Safety Advisory and Warning System (IVSAWS)

Volume IV: Appendices I Through K (Reference Materials)

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Invehicle Safety Advisory and Warning System (IVSAWS),

Volume IV: Appendices I Through K (Reference Materials)

U.S. Department of Transportation
Federal Highway Administration

Research and Development
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McLean, Virginia 22101-2296

FOREWORD

This report presents the results of a comprehensive study to identify candidate advisory, safety, and hazard situations where motorists would benefit from an Invehicle Safety Advisory and Warning System (IVSAWS). Functional specifications are also provided in sufficient detail to describe how these functions could be gradually incorporated into existing and future automotive vehicles. The IVSAWS, designed for rural, urban, and secondary roads, uses a proposed communication architecture based on transmitters placed on roadside signs and at roadway hazards to communicate with approaching vehicles equipped with IVSAWS invehicle radio receivers. This study will be of interest to transportation planners and engineers involved in motorist advisory and emergency communication systems.

Sufficient copies of the study are being distributed by the FHWA Bulletin to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.

Lyle Saxton
Director, Office of Safety and Traffic
Operations Research and Development

NOTICE

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16. Abstract

The Invehicle Safety Advisory and Warning System (IVSAWS) is a Federal Highway Administration effort to develop' a nationwide vehicular information system that provides drivers with advance, supplemental notification of dangerous road conditions using electronic warning zones with precise areas of coverage. The research study investigated techniques to provide drivers with advance notice of safety advisories and hazard warnings so drivers can take appropriate actions. The technical portion of the study identified applicable hazard scenarios, investigated possible system benefits, derived functional requirements, defined a communication architecture, and made recommendations to implement the system.

This volume is the fourth in a series. The other volumes in the series are:

FHWA-RD-94-061 Volume I: Executive Summary
FHWA-RD-94-190 Volume II: Final Report
FHWA-RD-94-191 Volume III: Appendixes A Through H (Reference Materials)
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Sysmbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in2	square inches	645.2	square millimeters	mm2
ft^2	square feet	0.093	square meters	m2
yd2	square yards	0.636	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2
		VOLUME		
fl oz	Fluid ounces	29.57	milliliters	mL
gal	gallons	3.765	liters	L
ft3	cubic feet	0.026	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
NOTE: Volumes greater than 1000 l shall be shown in m3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	9.454	kilograms	kg
T	short tons (2090 lb)	0.907	megagrams (or ‘metric ton")	Mg (or "t"
		TEMPERATURE (exact)		
oF	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Cefcius temperature	oC
		ILLUMINATION		
fc	foot-candles	10.78	lux	lx
fl	foot-Lamberts	3.426	candela/m2	cd/m2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply by	To FInd	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.08	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm2	square millimeters	0.0916	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	square kilometers	0.386	square miles	mi2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m3	cubic meters	35.71	cubic feet	ft3
m3	cubic meters	1.367	cubic yards	yd3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or ‘metric taon")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
oC	Cekius temperature	1.8C + 32	Fahrenheit temperature	oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch ,	lbf/in

SI is the symbol for the International System of Units. Appropriate rounding shoukf be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

Section **Page**

VOLUME I
LIST OF FIGURES

VOLUME I
LIST OF TABLES

VOLUME II
LIST OF FIGURES

Figure **Page**

VOLUME II
LIST OF FIGURES
(continued)

VOLUME II
LIST OF FIGURES
(continued)

VOLUME II
LIST OF FIGURES
(continued)

VOLUME II
LIST OF FIGURES
(continued)

VOLUME II
LIST OF TABLES

VOLUME II
LIST OF TABLES
(continued)

VOLUME II
LIST OF TABLES
(continued)

APPENDIX I:
INVEHICLE SAFETY ADVISORY AND WARNING SYSTEM (IVSAWS) COMMUNICATIONS TECHNOLOGY SELECTION

This appendix defines a baseline IVSAWS communication subsystem design that alerts drivers to advisory/safety signing and roadway hazards. Included in this appendix are the following communication-related analyses/simulations: a communication path geometry analysis, a driver alert distance analysis, a frequency selection and transmit power analysis, transmitter and receiver characterizations, computer modeling for key system parameters, and a transmitter directionality analysis. The results of the various analyses provided the key assumptions and design tradeoffs to specify an IVSAWS communication system architecture to support rural and urban highway driver alert/warning information requirements.

1.0 INTRODUCTION

The In-Vehicle Safety Advisory and Warning System (IVSAWS) program is a two year effort, partitioned into eleven tasks, with the goal of providing supplementary hazard warnings and others safety advisory information to motorists in both rural and urban settings.

Specific IVSAWS tasks include: establishing the program workplan (Task A); defining a prioritized list of hazards amenable to an IVSAWS solution (Task B); defining the IVSAWS baseline system architecture with emphasis on the communication link (Task C); procuring equipment to demonstrate the communication architecture (Task D); defining the baseline In-Vehicle Driver Warning System (Task E); fabricating the test version of the Driver Alert Warning System (Task F); performing human factors tests to determine the utility of key driver alert features (Task G); developing a system specification for the baseline IVSAWS design (Task H); and documenting the results of the entire program (Tasks I, J, and K).

IVSAWS will use radio transmitters placed at roadway hazards to communicate advisories and warnings to approaching vehicles quipped with radio receivers. This system will be capable of functioning as a stand alone communicator (direct roadside to vehicle communicator) and as an integral part of a much larger Intelligent Vehicle Highway System (IVHS).

Based on a prioritized list of IVSAWS related hazards defined in Task B, the Task C effort defined a baseline IVSAWS communication subsystem design that alerts drivers to advisory/safety signing and roadway hazards. Task C subtask rquirements include: a communication path geometry analysis; a driver alert distance analysis; a frequency selection and transmit power analysis; transmitter and receiver characterizations; computer modeling for key system parameters; and a transmitter directionality analysis.

The Task C report includes several sections which address all subtask requirements. The communication path geometry analysis, driver alert distance analysis and frequency selection' subtask requirements are addressed within the system baseline description, frquency analysis, range determination, and communication architecture selection portions of the Task C report The transmitter and receiver characterization subtask requirements are addressed within the waveform design, vehicle antenna evaluation, radio functional description, hardware implementation/cost estimates, and reliability potions of the Task C report. Computer modeling for key system parameters was performed to support the frequency selection, ranging, and communication architecture analysis/selection. The transmitter directionality analysis subtask requirements are addressed within the directionality issues portion of the Task C report.

The results of the individual Task C analyses provided the key assumptions and design tradeoffs to specify an IVSAWS communication system architecture to support rural and urban highway driver alert/warning information requirements. As part of the analysis, an IVSAWS receiver, using low cost readily available parts and Application Specific Integrated Circuit (ASIC) technology, was evaluated.

Task C outputs will be used in follow-on IVSAWS tasks to make procurement decisions for the IVSAWS demonstration system and to develop an IVSAWS functional system specification.

2.0 SYSTEM BASELINE DESCRIPTION

This section describes the IVSAWS baseline architecture. Detailed rationale for design decisions, especially logistic and human factors issues, are presented in subsequent sections. First the warning unit and the vehicle unit are described. Second, the communication architecture is described. Third, the system operation details are described Finally, the details of the message structure and waveform are presented.

IVSAWS consists of warning units and vehicle units. The warning units communicate safety advisories and hazard warnings to approaching vehicles equipped with IVSAWS units. The vehicle units exchange a series of messages with the warning units so that the vehicle units can determine their range from the hazard and their speed approaching the hazard The vehicle units then determine the proper time to notify the driver about the advisory or hazard Although the proper notification time can be determined from the physical parameters of the driving scenario, the performance measure is strictly a human factors issue. The proper notification time is a function of the hazard type, the closing speed, the vehicle type, and human reaction times. The IVSAWS design emphasizes the proper notification time because premature notification, excessive notifications, and late warnings will result in driver confusion and risk the credibility of this system.

The waming unit has three deployments — mobile, temporary, and permanent. The mobile deployment is a warning unit mounted on a school bus, an emergency vehicle, or a slow moving vehicle such as farm equipment. The temporary deployment is a warning unit placed at an accident site, a construction zone, or a road maintenance site. The permanent deploymenr is a warning unit placed at a location with a known infrastructure or environmental hazard Infrastructure hazards include railroad crossings, one lane bridges on two lane roads, and poorly designed intersections. Environmental hazards include fog areas, icy roads, and animal crossings. The warning units in all three deployments will use 12 Volt batteries as power sources.

The vehicle unit has two configurations — automobile and truck. The electronics for these two configurations are identical. Different response time and stopping distance information are programmed into the processor memory for the automobile and truck units. The vehicle units will use their 12 Volt batteries as power sources.

The general system characteristics for IVSAWS are listed in Table 2.1. The overall design philosophy has been to first determine the impact of human factors on the system functionality and then determine the communication architecture which will support these human factors considerations. As a result, the simple broadcast architecture of the proposal srawman design has evolved to a bidirectional communication architecture with ranging in the baseline design.

Table 2.1 IVSAWS System Parameters

- Simple Warning Unit Operation
- Audio / Icon / Text Driver Alert
- Minimum Alert Distance of 1 Kilometer
- Optimal (Variable) Alert Distance
- Flexible Advisory Message
- Bi-directional Communication with Ranging
- Slotted Aloha Protocol
- FCC Allocation in 420 to 450 MHz
- 4.9 15 MHz Spread Spectrum
- Omni Directional Antennas
- 4 Watt Transmitters
- 12 Volt Battery Power Source
- 100 dBm Receiver Sensitivity
- CRC Error Detection

The warning units and vehicle units arc composed of essentially the same subassemblies, as seen by comparing Figure 2.1 and Figure 2.2. Both the warning unit and the vehicle unit have a frequency conversion module, a digital correlator processor, and a microcontroller. The frequency conversion module translates the radio signal between its assigned location in the frequency spectrum where the signal propagates over the link and baseband where the information is placed on or extracted from the waveform Currently, the most feasible frequency allocation is in the 420 MHz to 450 MHz band. The digital correlator processor extracts the digital information from the spread spectrum waveform during message reception and encodes the information onto the 4.915 MHz spread spectrum waveform during message transmission. The microcontroller operates the radio by organizing the protocols used for message transfer and performs tasks specific to the IVSAWS unit type.

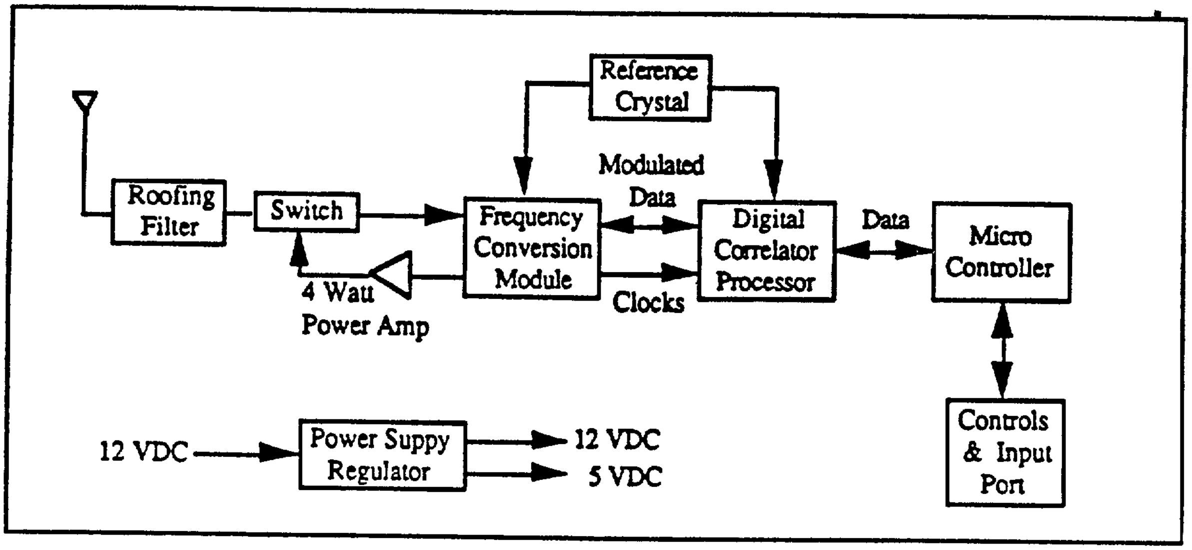

Figure 2.1. Block Diagram for IVSAWS Warning Unit.

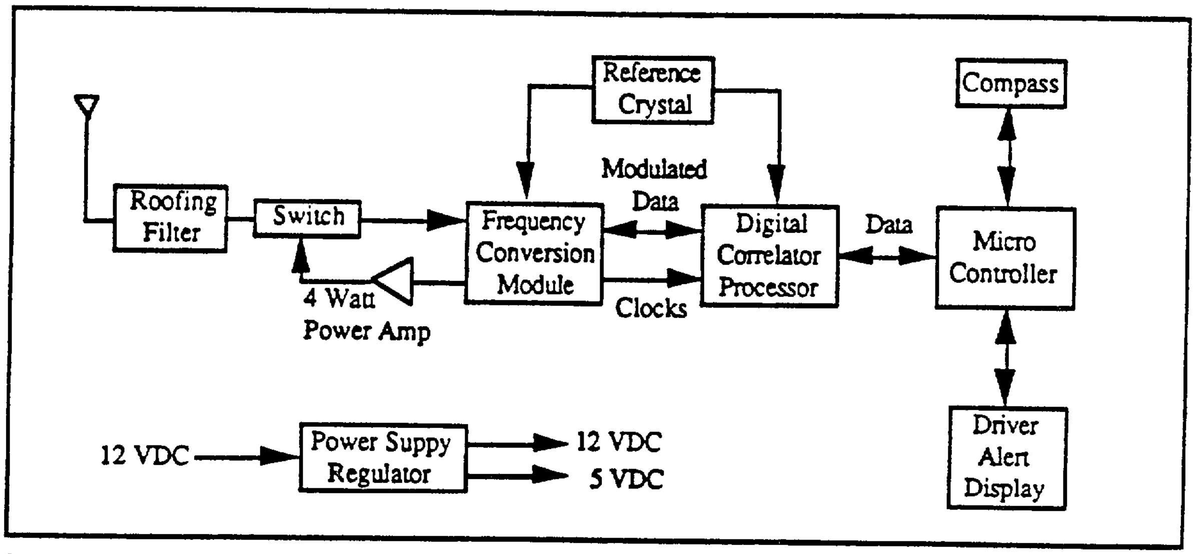

Figure 2.2. Block Diagram for IVSAWS Vehicle Unit.

Due to the different roles of the warning unit and the vehicle unit, the interface equipment and the respective microcontroller processing algorithms are different. The warning unit has an input port for supplying directional data or loading new advisory messages. The vehicle unit has an electronic compass and a driver alert module consisting of an icon display on the dashboard, a speaker, and a CRT display in the car's instrument console. The processing algorithms in the warning unit microcontroller initiate advisory broadcasts and respond to range queries from vehicle units. The processing algorithms in the vehicle unit initiate range queries, compute range data, utilize electronic compass data, and determine the optimal time to present the advisory information to the driver on the display system.

Additional functions, which are common to both the warning unit and the vehicle unit, support the three major subassemblies. An antenna, roofing filter, switching module, and power amplifier are required for the frequency conversion module. The omni-directional antenna is specifically designed for dual band operation with both the car AM/FM radio and the IVSAWS link. The correlator processor requires a Random Access Memory circuit for message preamble detection. A crystal oscillator establishes the basic timing for the microcontroller. Finally, a power supply provides the voltages required to operate the radio.

Ideally, the entire IVSAWS units would be manufactured as one Application Specific Integrated Circuit (ASIC). All digital circuit functions operate at clock frequencies less than 40 MHz. Hence, the digital portion of the units are well within the state of the art in Very Large Scale Integration (VLSI) implementation using CMOS circuitry. However, RF circuitry does not have the same degree of standardization or integration capability as digital CMOS circuitry. Therefore, the IVSAWS units will consist of several moderately integrated RF modules and one highly integrated digital module. The resulting unit cost in 100,000 quantity lots is estimated at 113 dollars. The driver alert module is not included in this cost estimate. The total failure rate for these units is estimated at $33.68 \cdot 10^{-6}$ per hour. This failure rate corresponds to a mean time between failure of 29,690 hours. The average vehicle requires 10,000 driving hours to accumulate 200,000 miles so the mean time between failure is nearly three times greater than the optimistic lifetime of the average vehicle.

IVSAWS baseline design has bidirectional communication. Bidirectional communication enables the vehicle unit to obtain information necessary for the processor in the vehicle unit to compute range from the warning unit and to compute closing speed (range rate) to the warning unit. The vehicle unit uses direction, vehicle speed, vehicle type, and hazard type to determine the proper time to alert the driver. The warning is stored in the vehicle units processor until the proper alert time occurs and then is presented to the driver. The initial warning is dual mode using both a visual icon and an audible message. Supplemental information can be activated by the driver at their discretion. The supplemental information is presented to the driver on the vehicle's CRT after the driver activates an information button.

The range information is obtained by measuring the elapsed time between a message and its acknowledgement. Figure 2.3 illustrates this ranging process. The ranging computation algorithms and the waveform to support the ranging process are proven technology from the Position Location and Reporting System (PLRS). PLRS was designed and manufactured by Hughes Aircraft Company for the United States Army and Marine Corps.

To start the process, a warning unit transmits its advisory message at one second intervals plus/minus some randomly selected jitter. The advisory message includes the warning unit's identification, hazard severity, and directional information. All vehicle units within communication range process this message. Each vehicle compares the direction in the message with the vehicle heading from the electronic compass. If the directional information indicates that the advisory message applies to a particular vehicle, then that vehicle unit responds by transmitting a Round Trip Timing Interrogate (RTT-I) message. RTT-I is addressed to the warning unit and contains that vehicle unit identification. The warning unit responds to that specific vehicle by transmitting a RTT Response message (RTT-R). RTT-R is addressed to a specific vehicle unit and contains the warning unit identification. This particular vehicle unit computes its range by first measuring elapsed time between the transmission of RTT-I and the reception of RTT-R The elapsed time is adjusted to account for processing time at both units. The elapsed time is then converted to distance. All directionally appropriate vehicle units within a warning units communication zone perform this ranging process.

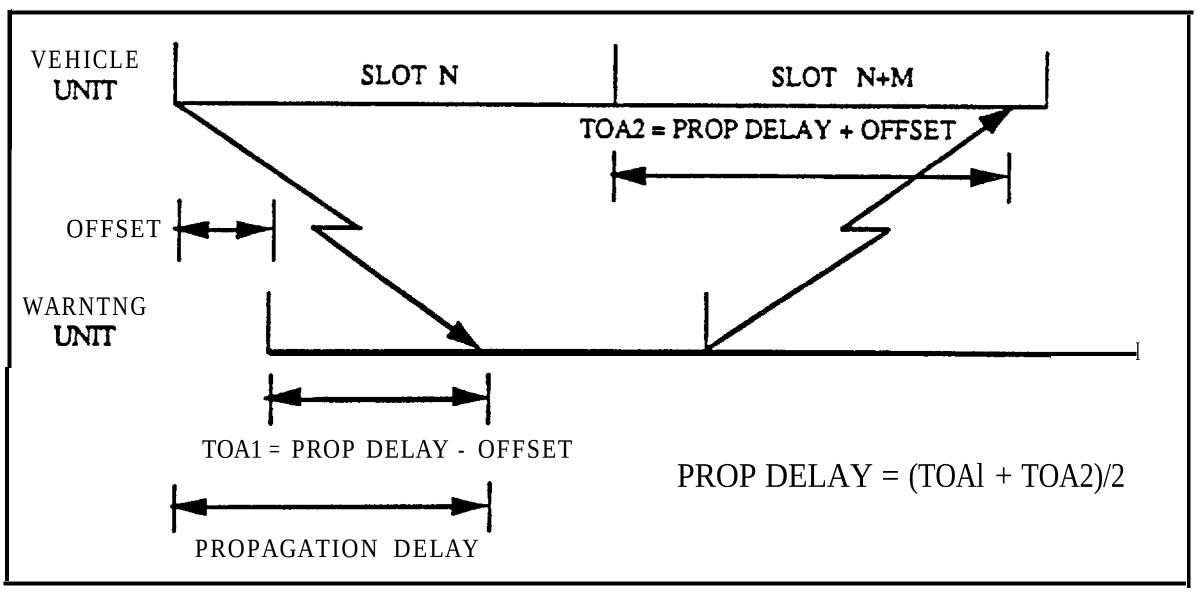

Figure 2.3. Ranging using Round Trip Timing Process.

Range rate information is obtained by performing a second range measurement. The closing speed is the relationship between the range difference and the elapsed time. To provide meaningful resolution for the vehicle speeds involved, the elapsed time should be 5 seconds.

The warning unit performs this ranging process with all vehicle units within its communication range. The system loadings are quite different under initial conditions and steady state conditions. Initial conditions occur when the warning unit is first activated, potentially in an area already heavily congested with vehicles. Steady state conditions occur when the warning unit is responding to the normal ingress and egress of traffic, potentially at a multi-lane interstate with high-speed, closely spaced vehicles. Contention among the vehicle unit responses are prevented in two ways. First, the warning unit has variable power settings. Second, the IVSAWS communication network architecture is a variant of the slotted Aloha protocol.

The warning unit has adjustable transmission power settings up to the maximum 4 Watts transmission power. In the mobile and temporary deployments, the transmission power starts at the lowest setting and automatically increases gradually to the maximum power. When the warning unit is first activated, the initial transmission power is 2.25 dBm. Every 2 seconds after activation, the warning unit increases the transmitted power by 2.25 dBm until the maximum 36 dBm power is transmitted. Each time the power is increased, another subset of the vehicles within the maximum communication range are processed in an orderly fashion thereby minimizing contention. The maximum 36 dBm transmitter power quates to a 1 kilometer transmission range in dense foliage. In the permanent deployment, the transmission power can be set at the appropriate level for the given terrain conditions.

The worse case steady state processing load is 8 new vehicle arrivals and departures per second. The 8 vehicle arrival rate is derived from the conditions of an 8 lane interstate highway at 80 miles per hour with 10 feet spacing between vehicles. In order to provide rapid network access under very dynamic ingress and egress conditions without excessive access contention, the IVSAWS communication network architecture is a variant of the slotted Aloha protocol. Time is divided into 1 second frames. As shown in Figure 2.4, each frame has an advisory message slot, a vehicle processing slot, 513 round trip timing (RTT) slots, and a jitter slot. The advisory message slot is 6.875 milliseconds. The vehicle processing slot is 0.7 msec. Each RTT slot consists of 0.547 msec RTT-I, 0.7 msec warning unit processing, and 0.547 msec RTT-R for a total length of 1.794 msec. The jitter slot is 72.103 msec.

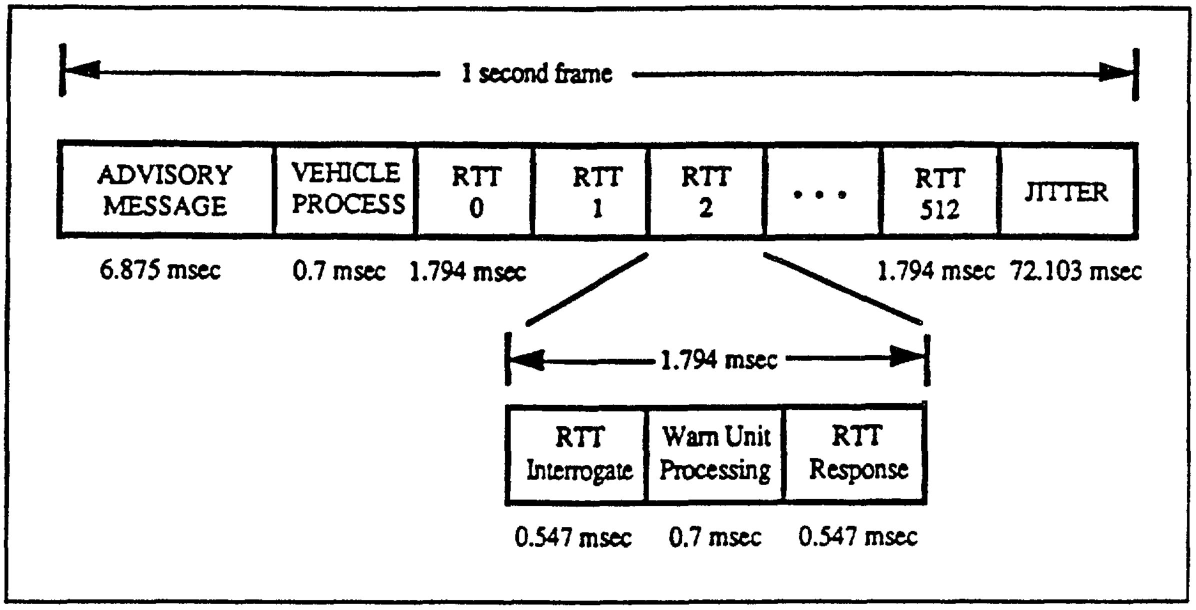

Figure 2.4. IVSAWS Slotted Aloha Structure.

Frame demarcations are relative to the warning unit. A frame begins when a warning unit transmits a hazard or advisory message. The message includes the warning unit's identification, hazard severity, and directional information. All vehicle units within communication range process this message. All vehicle units to which the directional information apply then transmit a RTT interrogate message in RTT slot 0. If only one vehicle unit responds in slot 0, then there isn't any contention, otherwise the strongest signal survives. The warning unit actions are based on whether or not it senses any transmissions in slot 0. If slot 0 does not contain any transmissions, then no vehicles are in the warning area or all vehicles have completed their ranging process, so the warning unit goes into a wait state to conserve power. If slot 0 contains a transmission, then the warning unit provides a RTT response in the remainder of slot 0. The warning unit will listen for other RTT Interrogates during the remainder of the 1 second frame. Meanwhile, the vehicle units are selecting a random number between 1 and 512. Any vehicle which does not receive a RTT Response in slot 0 specifically addressed to it will attempt the ranging process again in the RTT slot corresponding to the random number selected.

The requirement for directional warning notification arises from specific scenarios. On a rural 2 lane undivided highway or on any rural and urban street, anything which affects one direction of traffic will affect the other direction of traffic, so directional information is not required. On rural and urban divided highways, something which affects one direction of traffic need not affect the other direction of traffic. Similarly, at an overpass, something which affects one roadway need not affect the other roadway. The method for incorporating the directional information into the advisory message will depend on the warning unit deployment For the permanent and temporary deployments, the message will be degenerated by a menu driven application on a personal computer and then loaded into the warning unit via an RS-232 port For the mobile deployments, the vehicle operator will have a small input console for specifying omnidirectional or direction specific. The advisory message has 16 bits designated as a direction field. Each bit represents a 22.5 degree sector of the compass. A directional sector is active if the corresponding bit is a one. The vehicle unit compares the activated sectors with the vehicles heading from its electronic compass. If the vehicles heading is within the activated sectors, then the vehicle unit performs ranging operations and alerts the driver at the proper time.

The proper time to present the safety advisory or hazard warning to the driver is a function of five items — a warning generation time, two different driver perception times, a warning effectiveness period, and a hazard avoidance maneuver distance Note that any elapsed times ultimately translate into additional warning distance from the hazard as a function of the vehicle speed. The upper limit on warning generation time is 5 seconds for a speech synthesized two sentence English alert message. The first perception time is the 2.5 seconds required for the driver to comprehend an IVSAWS alert. The second perception time is the 2.5 seconds required for the driver to recognize the hazard once the hazard enters the driver's field of vision. The warning effectiveness period is the 6 seconds during which a driver can initiate an action (e.g., remove foot from accelerator) that will increase the probability of a successful hazard avoidance maneuver. The hazard avoidance maneuver distance depends on the vehicle type, the closing speed, and the hazard severity. The different hazard severities result in three corresponding reactions — increased attention, lane change, and full stop. Increased attention is needed when a maintenance crew is off to the side of the road. A lane change is required to go around a slow moving vehicle or to move over for an emergency vehicle. A full stop is required when the road is blocked due to an accident. Tables 2.2 and 2.3 present the alert distances from the hazard for the specified hazard severity and vehicle type. The maximum required alert notification distance is 3770 feet (1150 meters) for a speeding commercial truck with bald ties that must stop on wet pavement. Other scenarios require corresponding less advanced warning.

The driver alert distance in the worse case hazard scenario provides the maximum communication range of the IVSAWS communication link. This worse case scenario includes maximum range, 98th percentile speed, heavy vehicle, wet pavement, and terrain geometry features such as foliage loss. The IVSAWS link budget under these conditions is given in Table 2.4. Link Margin exists whenever the terrain geometry or hazard scenario is not worse case.

Table 2.2 Automobile Driver Alert distances

	Notification Distance (feet)		
Vehicle Speed (mph)	Increased Attention	Lane Change	Full Stop
40	940	1200	1160
50	1170	1470	1550
60	1410	1750	2030
70	1660	2040	2600
80	1880	2300	3150

Table 2.3 Commercial Truck Driver Alert Distances

	Notification Distance (feet)		
Vehicle Speed (mph)	Increased Attention	Lane Change	Full Stop
40	940	1200	1320
50	1170	1470	1815
60	1410	1750	2400
70	1660	2040	3070
80	1880	2300	3770

Table 2.4 Link Budget for Worse Case Scenario

COMPONENT	VALUE	NET
Transmit Power	+36.0 dBm	+36.0 dBm
Tx Antenna Gain	0.0 dBm	+36.0 dBm
Tx Implementation Loss	-2.0 dB	+34.0 dBm
Free Space Loss	-86.1 dB	-52.1dBm
Foliage Attenuation (1km)	-30.8 dB	-82.9 dBm
Noise abouve Galactic	-4.0 dB	-86.9 dBm
Rx Antenna Gain	0.0 dBI	-86.9 dBm
Rx Implementation Loss	-2.0 dB	-88.9 dBm
Rx Sensitivity	-100.0 dBm	+11.1 dBm
Demodulation Threshold	11.1 dB	0.0 dBm

The driver alert module design and warning procedures will be finalized after the human factors tests in Task G. For the preliminary design, the driver alert module is an icon display on the dashboard, a speech synthesis unit with speaker, and a CRT display in the instrument panel. When the vehicle unit microcontroller determines that the proper waming time has arisen, a visual and audio ques are simultaneously activated so that the driver receives a bi-sensory warning. The visual cue will be a special IVSAWS pictogram or the words "HAZARD ALERT". The audio ques will be a brief, preferably less than 10 words, situation specific alerting message. Sample alerting messages are "emergency vehicle approaching","consuuction zone ahead", and "disabled vehicle ahead". In addition to the brief alerting message, the system will also have detailed action advisory messages which recommend driver actions and supply specific details of the impending hazard situation. These messages will be presented to the driver on the CRT display only at the drivers request. The driver requests the details of the action advisory by pressing an information button near the CRT display.

The communication link supports the ranging function and variable message content feature of the system by using two types of messages. Both the RTT and Alert message types contain fields for preamble, time refine, system identification, and warning unit identification. The RTT message also contains a field for vehicle unit identification. The alert message also contains fields for hazard type, direction indicators, free text, and error detection. The bit allocations for each of these message types are given in Table 2.5 and Table 2.6.

Table 2.5. Field Allocations for Alert Message

Alert Message Field	Bits
Preamble	16
Time refine	8
System Type	8
Warning Unit Identification	16
Hazard Type & Various Flags	16
Direction Indicators	16
Free Text	960
Error Detection	16
Total	1056

Table 2.6. Field Allocations for RTT Message

RTT Message Field	Bits
Preamble	16
Time refine	8
System Type	8
Vehicle Unit Identification	36
Warning Unit Identification	16
Total	**84**

The 1056 bit Alert Message and 84 bit RTT' messages are converted from digital baseband data to noncoherent digital modulation RF by a sequence of steps. The message data is differentially encoded using Differential Phase Shift Modulation. Each encoded bit is then spread (multiplied) by a fixed 32 bit sequence. The resulting 4.9152 MHz bit rate sequence is input to a conventional heterodyne mixer. After the upconverting to the intermediate and final carrier frequencies, the mixer produces a 4 Watt constant amplitude phase modulated spread spectrum signal at 420.25 MHz. At 32 chips per bit and a 4.9152 MHz chipping rate, the 1056 bit Alert Message requires 6.875 milliseconds to transmit. Similarly, the 84 bit Alert Message requires 0.546375 milliseconds to transmit.

When in receive mode, the signal at the receiver antenna is convened from RF to baseband using two downconveners in a conventional heterodyne mixer. The second mixer splits the signal equally but shifts one of the two outputs by 90o resulting in an in-phase (I) and quadrature (Q) channels. Two analog to digital converters, operating at 4 times the chip rate or 19.6608 MHz, sample the I and Q channels and output 2 bit amplitude samples. The samples are fed into the preamble correlator which is looking for the known pattern of preamble bits at the start of a message. When the signal samples and the stored pattern agree sufficiently, the preamble correlator declares message detection and synchronizes message timing. After preamble detection, the preamble correlator is deactivated and the digital processor removes the 32 bit spreading code from the incoming chip stream. A code tracking circuit refines message timing during demodulation to +/-1/8 of a chip period. The despread data is differentially decoded and the message data is given to the microcontroller to process.

3.0. FREQUENCY BAND SELECTION

3.1. OVERVIEW

IVSAWS provides hazard warning and other advisory information to motorists in both rural and urban settings. Transponders at the appropriate locations transmit messages to receiver units in IVSAWS equipped automobiles. The message information is then presented to the driver (both aurally and visually). The Federal Communication Commission (FCC) regulates transmission power and frequency bandwidth of any radiating system operating in the public domain. The required transponder power is a fundamental function of three items — communication range, atmospheric losses, and terrain losses. The frequency bandwidth is a function of data rate and other system functions. Several analyses were performed in parallel to obtain these parameters (see Figure 3.1). A computer model used these parameters also in order to determined an upper bound on the communication path losses for different combinations of link ranges, terrain features, and carrier frequencies. The combined impact of the link loss analysis results, IVSAWS cost considerations, and FCC regulations yielded a final set of recommended frequency bands for the IVSAWS system.

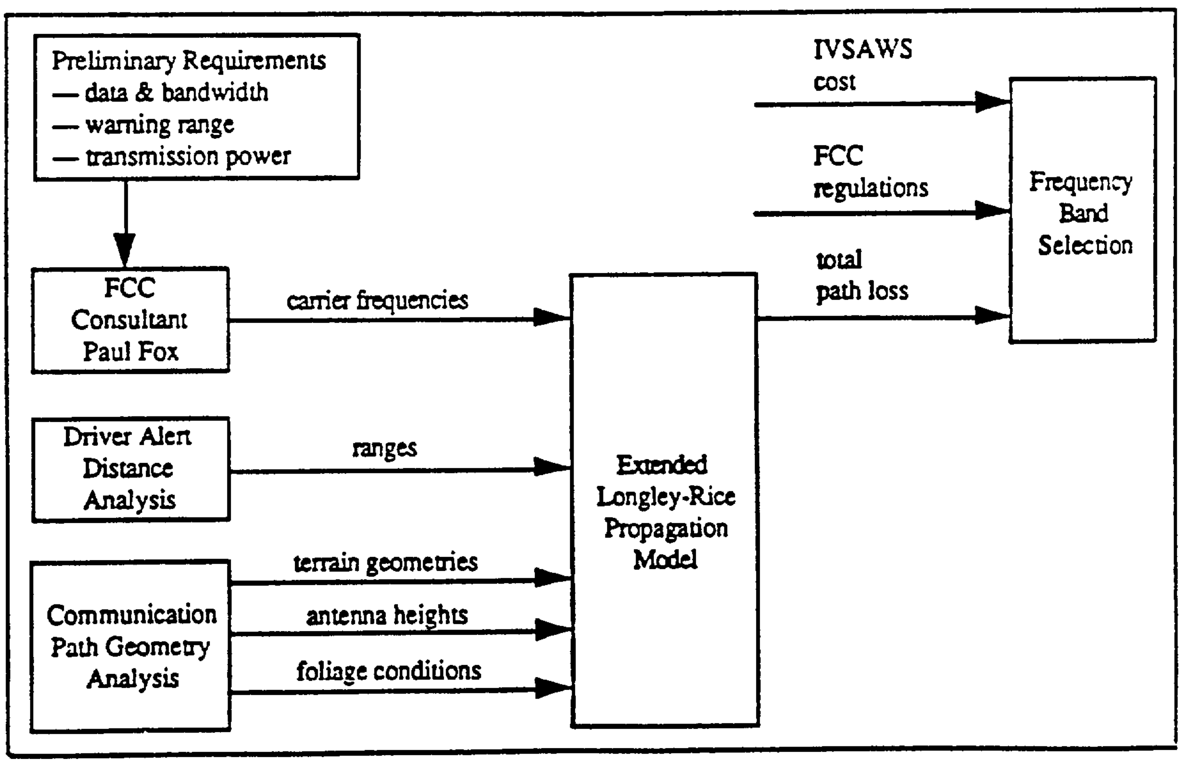

Figure 3.1. Task Flow for IVSAWS Frequency Band Selection.

3.2. FCC CONSULTANT

The search for frequency bands appropriate to the IVSAWS role was largely performed by Paul Fox of Telecommunications Consulting in Washington, DC. First, Fox familiarized himself with the available vehicle telemetry systems. Second, Hughes provided Fox with a set of preliminary system requirements. Third, Fox examined the electromagnetic spectrum for compatibility with IVSAWS bandwidth and transmission power requirements. Frquency bands occupied by “immovable objects” based on FCC regulations wen eliminated from consideration. Fourth, Fox identified the remaining frequency bands with sufficient bandwidth. Mr. Fox’s final report is given in Appendix A.

The available vehicle telemetry systems are TRAVTEK, Teletrack, and Mertz. These systems all currently use the 902 to 928 MHz frequency band. Fox was not familiar with the Hughes Vehicle Location System (VLS). Fox’s primary interest was in the frequency band used by VLS and how the frequency allocation was obtained. VLS is a prototype system that is an outgrowth of the Hughes Position Location and Reporting System (PLRS) and hence currently uses the same military 400 to 450 MHz frequency band allocation.

The preliminary bandwidth requirements were obtained by considering: 1) combined IVHS - IVSAWS requirements, 2) IVSAWS only with ranging, and 3) IVSAWS only without ranging. While IVSAWS can be a stand alone system, its value to the driver will be greater and the costs lower if NSAWS is part of a larger intelligent Vehicle Highway System (M-IS). IVHS will actually be composed of many systems ultimately requiring large bandwidth to support high data rates for detailed map information and vehicle guidance. For this type of data and the corresponding update rates, the IVHS bandwidth estimate is a minimum of 25 MHz. For IVSAWS with ranging, PLRS is a suitable reference point to determine bandwidth. PLRS uses a 5 MHz spread spectrum waveform to perform ranging between units. A 5 MHz waveform has a chip duration of 200 nanoseconds. At 1 foot per nanosecond, the initial range estimate is accurate to 200 feet Early-late tracking circuitry then refines the PLRS accuracy to 1/10 of a chip or 20 feet. On the other hand, if ranging is not included then only modest waveform spreading to gain noise immunity would be required. In FCC allocations, normal narrowband channels are 25 to 50 KHz wide. Estimating an IVSAWS non-ranging transmission as a 100 bit message once per second with an on the air rate of 1 KHZ yields 17 dB processing gain. These preliminary bandwidth requirements are listed in Table 3.1. Mr. Fox was directed to focus primarily on the IVSAWS requirements but to provide some guidance of the impact of IVHS requirements on frequency band selection.

Table 3.1 Preliminary Requirement for Frequency Band Search

Allocation	Nation-wide
Bandwidth - combined - IVSAWS only	25 MHz minimum 1MHz to 5 MHz
Transmitter EIRP	46 dBm
Receiver Antenna Gain	0 dBI
Communication Range	2.7 kilometers

The preliminary transmission power was estimated by considering communication range and foliage loss. A worse case hazard scenario upper bounds the IVSAWS communication range. The worse case hazard situation involves a high speed emergency vehicle approaching a high speed commercial truck. Both vehicles are travelling at 80 mph, a 99th percentile speed. The emergency vehicle has an IVSAWS warning unit and the commercial truck has an IVSAWS vehicle unit. Furthermore, the truck with nearly bald tires must come to a full stop on wet pavement. Under these conditions, the preliminary communication range estimate is 2.7 kilometers. Section 4 of this report discusses the derivation of actual 1 kilometer IVS AWS communication range. Combining the free space loss for 2.7 kilometers at various carrier frequencies, a nominal receiver sensitivity of -100 dBm, and approximately 40 dB of foliage attenuation yielded a EIRP estimate of 46 dBm. EIRP, Equivalent Isotropically Radiated Power, is the product of the power into an antenna and the gain of the antenna relative to an isotropic antenna The 46 dBm EIRP estimate was for a 10 Watt transmitter with a 6 dB1 antenna gain. These preliminary requirements are also listed in Table 3.1.

A single national channel was desired. While state-wide channels might be acceptable, any system that operated on multiple channels with variable local restriction on some or all of these channels was unacceptable. Hence, although most drivers spend nearly their entire time in the same county or state, the operational and logistic impact of state-wide or county-wide IVSAWS frequency allocations were deemed inappropriate for the system design.

After examining the electromagnetic spectrum for compatibility with IVSAWS bandwidth and transmission power requirements and after eliminating frequency bands occupied by “immovable objects” based on FCC regulations, Mr. Fox identified the frequency band candidates shown in Table 3.2. From strictly an allocation point of view, the most promising frequency bands for IVSAWS are the bands currently reserved for the cellular phone advanced paging systems and the Low Earth Orbit Satellites. These two systems are under development so that compatibility issues for co-channel utilization could be resolved before these systems and IVSAWS complete development and deployment Other frequency bands might be more favorable for technical reasons but the cost to reaccommodate other systems in different frequency bands is economically prohibitive in most instances. Due to the extremely large bandwidth of IVHS relative to currently deployed systems, the best IVHS recommendation is that the Federal Highway reserve a portion of the 3.1 GHz to 3.7 GHz Executive Branch Spectrum that will be transferred to civilian use under proposed legislation.

Table 3.2. Candidate IVSAWS Frequency Bands

FREQUENCY	FUNCTION
42 - 47 MHz	Highway Maintenance Channels
420 - 450 MHz	Military Radar
450 - 470 MHz	Public Safety and Land Mobile
825 - 845 MHz	Cellular Phones
870 - 890 MHz	Cellular Phones
901 - 902 MHz	Civilian Fixed Site Communication
902 - 928 MHz	FCC Part 15 Spread Spectrum
930 - 931 MHz	Advance Paging Systems
940 - 941 MHz	Land Mobile Reserve (promised)
1340 - 1400 MHz	Radiolocation and Radionavigation
3100 - 3700 MHz	Executive Branch Reallocation

Based on the contents of Table 3.2, seven carrier frequencies were used as inputs to the extended Langley Rice propagation model. The 7 carrier frequencies are 47 MHz, 425 MHz, 850 MHz, 915 MHz, 930 MHz, 2440 MHz, and 3400 MHZ,

3.3. TERRAIN GEOMETRIES

The local landscape can present natural obstacles which interfere with the communication link. This interference is represented in the form of additional absorption losses. Four terrain geometries were selected as part of the process for recommending a frequency allocation for IVSAWS. The geometries had to be typical of the United States and stressful of the communication link. The selected geomeuies are: A) a straight high speed road over flat surface, B) a curved road with steep elevation through leafy trees, C) a road highway through rolling hills, and D) a curved road with interleaving mountains. The communication parameter that each of these geometries stressed are given in Table 3.3. Appendix B contains the details of the communication path geometry analysis, ENB C-l-l.

Table 3.3. Terrain Geomeuy Selection

TERRAIN GEOMETRY	PARAMETER STRESSED BY GEOMETRY
Straight flat high speed highway	Communication range
Curved highway though leafy trees	Foliage attenuation, Antenna pattern
Highway through rolling hills	Diffraction loss due to contour
Curved road with interleaving mountains	Diffraction loss due to contour

Geometry A is a straight road over flat surface. Site selection for this geometry is somewhat arbitrary because straight and flat stretches of highway are numerous. Case 6 from the IVSAWS Task B report was chosen to model this geometry. The involved stretch of road is U.S. Highway 23 near its intersection with Michigan Highway 14.

Geometry B is a curved road through trees with a steep elevation angle. U.S. Highway 89 Alternate, approximately 13 miles north of Sedona, Arizona was selected to emulate this geometry. At the northern end of Oak Creek Canyon, the highway has sharp curves and covers a significant elevation differential, 700 feet in 2 miles. Through this region, the posted speed limit drops to 15 mph. Foliage along this route is dominated by dense oak and pine woods.

Geometry C is a highway through rolling hills. U.S. Highway 385, approximately 1 mile south of Hot Springs, South Dakota was selected to emulate this geometry. The intervening hills range from 60 feet to 164 feet in height.

Geometry D is a curved road with interleaving mountains. Interstate 90, through Snoqualmie Pass, near Seattle, Washington, was selected to emulate this geometry. This area is a well travelled ski resort area.

Note that Geometry A is line-of-sight (LOS), that Geometry C is LOS or nearly LOS, and that Geometries B & D are both non-LOS.

3.4. Description of Extended Longley Rice Propagation Model

Having separately determined the relevant communication ranges, carrier frequencies, and terrain geometries, these three factors can be combined to determine an overall link loss for the communication path. The impact of these factors on communication path losses are quantified by various analytical and empirical results. These results have been incorporated into the Langley-Rice propagation model. The Langley-Rice propagation model is a computer simulation that provides realistic and representative calculations for communication link losses under all specified conditions.

Under the sponsorship of the Environmental Science Services Administration in the U.S. Department of Commerce, Langley and Rice developed a model for predicting median radio transmission loss over irregular terrain. The Longley-Rice model has been carefully validated with experimental data. The Langley-Rice propagation model has been a standard for the US Army for more than 10 years. Hughes Aircraft Company has extended this propagation model to include the effects of foliage attenuation. The Hughes Aircraft Company Langley Rice Model (HACELR) has also been carefully validated with experimental data. The HACELR is applicable for radio frequencies above 20 MHz.

The propagation model input parameters are the frequency, antenna heights, terrain conditions, foliage conditions, and communication ranges. The terrain and foliage conditions can either be specified by digitized maps for the area of interest or be characterized as a two dimensional surface with specified roughness. From the input parameters, the propagation model calculates the median reference values of attenuation relative to the uansmission loss in free space as a function of distance.

The algorithm in the propagation model considers both line-of-sight and over-the-horizon paths. For line-of-sight paths, the calculated attenuation is based on two-ray theory and an extrapolated value of diffraction attenuation. For over-the-horizon paths, the calculated attenuation is the smaller of either diffraction attenuation or forward scatter attenuation. For both path types, the predicted attenuation has been made sufficiently general to provide estimates of transmission loss expected over a widely diverse set of conditions. Attenuation predictions have been tested against data for numerous combinations of frequency, path lengths, antenna heights, and all types of terrain from very smooth plains to extremely rugged mountains. The propagation model data base includes more than five hundred long-term recordings and several thousand mobile recordings in the United States at frequencies from 20 MHz to 1 GHz.

The input parameters for the propagation model are frequencies, communication ranges, antenna heights, terrain conditions, and foliage conditions. The numerical values for the frequencies and communication ranges were derived as specified above. The transmitter and receiver antenna heights were set to 1 meter in order to model the effects of a worst case (with respect to link loss) mobile-transmitter IVSAWS deployment. The numerical values for the terrain and foliage conditions must be derived. Actual digitized terrain and foliage maps were not readily available for the latitudes and longitudes in the Geometry A through Geometry D areas. Instead digitized maps of representative terrain containing each geometry's key features formed the propagation model's terrain and foliage input data. Results for the non-LOS scenarios are assumed to upper bound the IVSAWS link loss estimates because of the severe nature of the communication path geometrics

3.5. RESULTS FROM EXTENDED LONGLEY RICE PROPAGATION MODEL

The path attenuation results from the propagation model for Geometry A are presented in Figure 3.2. Similarly, the path attenuation results for Geometries B, C, and D are presented in Figure 3.3, Figure 3.4, and Figure 3.5, respectively.

The impact of the path attenuations can be evaluated by considering an example situation. From the analyses presented in Section 4 of this report, the communication link is one kilometer or less. Furthermore, assume a receiver sensitivity of -100 dBm at a 10-3 bit error rate (BER). This is a nominal value for receiver sensitivity at this BER. Finally, consider a transmitter with a 36 dBm EIRP. This 36 dBm EIRP is an estimate of the IVSAWS maximum permissible transmitter power for the worse case condition that IVSAWS will be required to co-utilize a channel with another system. Under these assumptions, the maximum tolerable combined free space and foliage path loss is 140 dB.

In flat terrain (Geometry A), at the one kilometer distance the path attenuation varies from 85 dB at 47.2 MHz to 136 dB at 3400 MHz. In rolling hills (Geometry C), at the one kilometer distance the path attenuation varies from 85 dB at 472 MHz to 125 dB at 3400 MHZ. Thus, for the example transmitter power and receiver sensitivity, the Scenario A and C results indicate that reliable communication should be attainable at any of the frequencies considered provided the link is nearly LOS and the required range is one kilometer or less.

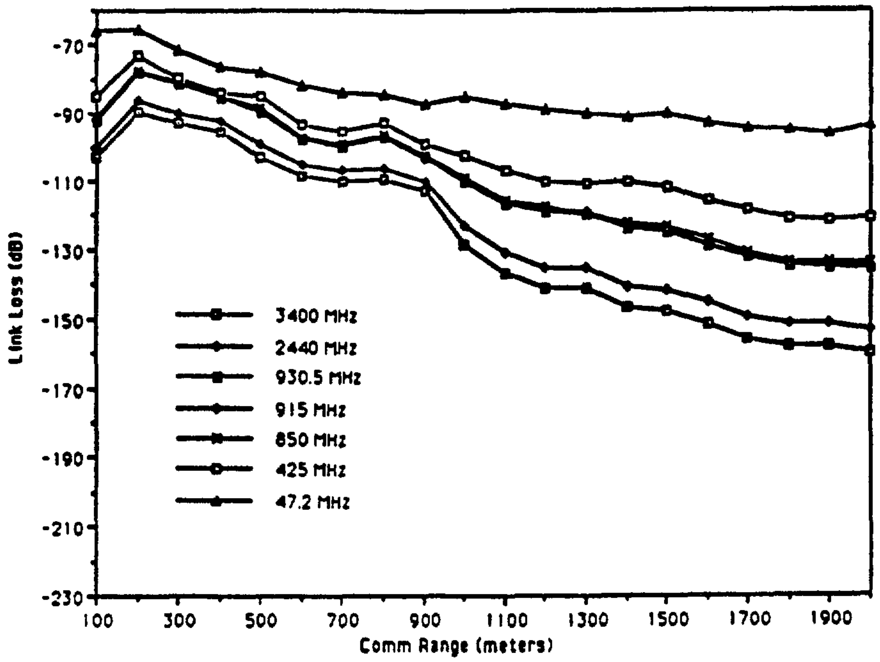

Figure 3.2. Link Losses for Geometry A — Straight Road over Flat Surface

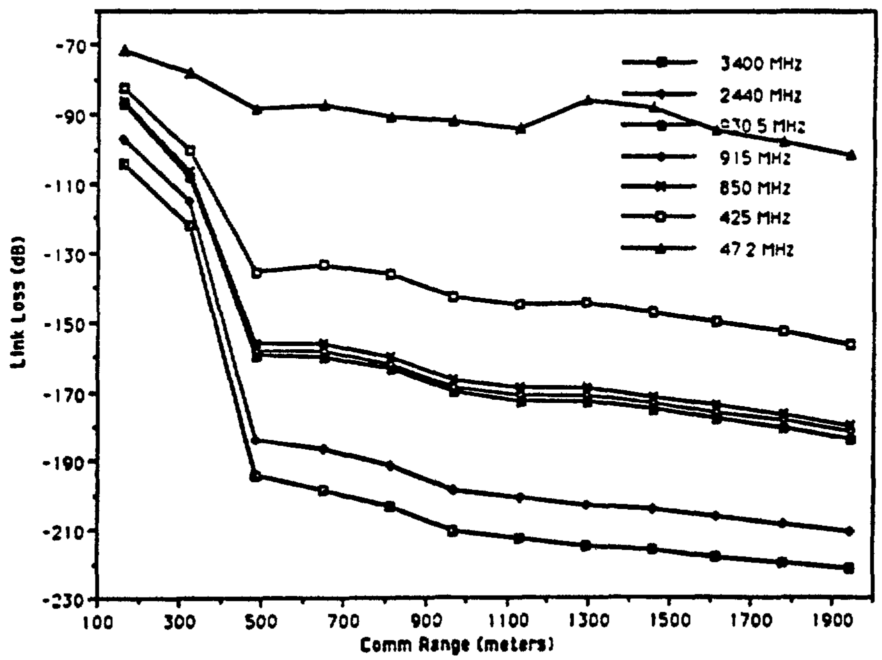

Figure 3.3. Link Losses for Geometry B — Curved Highway through Trees

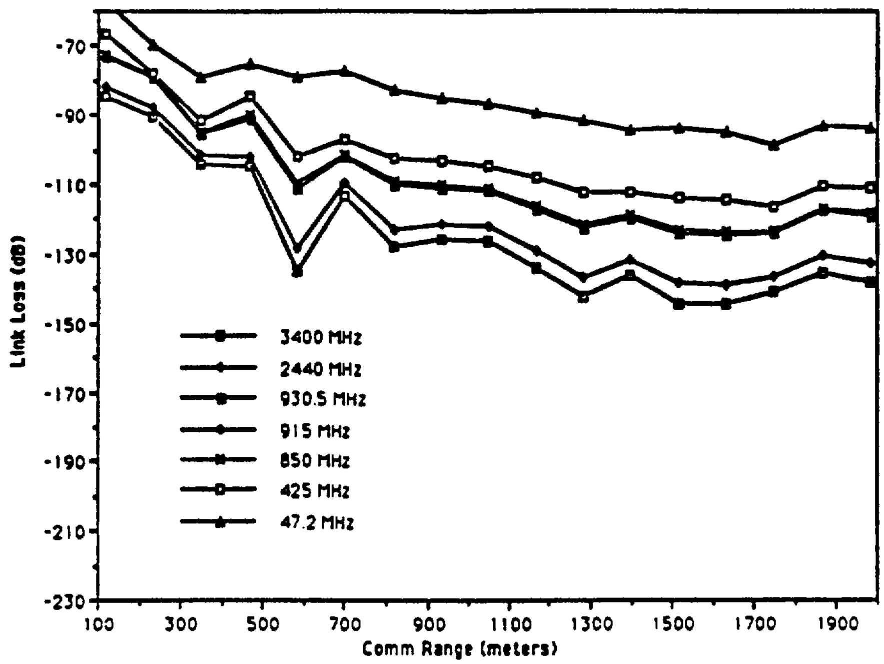

Figure 3.4. Link Losses for Geometry C — Highway through Rolling Hills

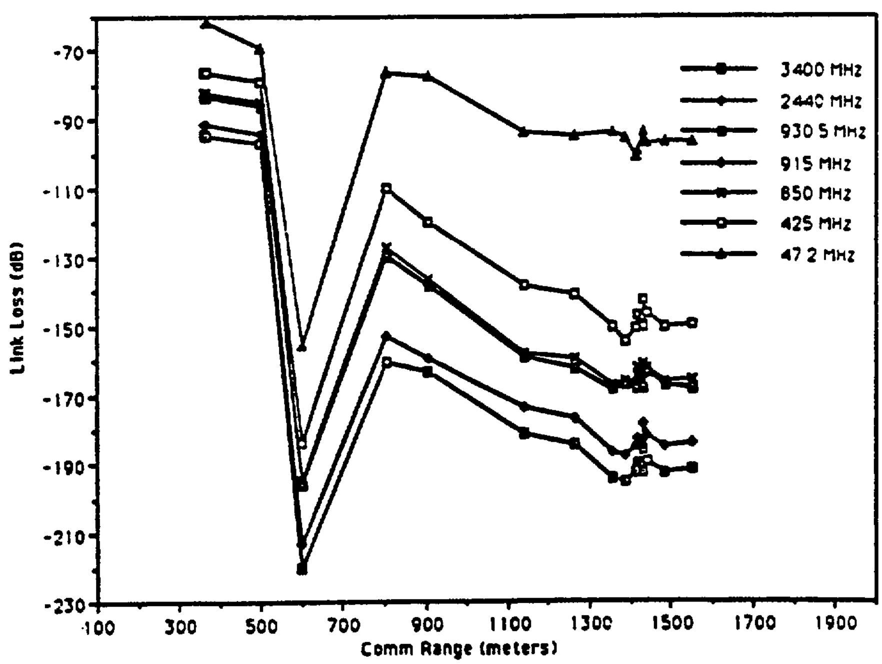

Figure 3.5. Link Losses for Geometry D — Curved Road with Interleaving Mountains

In terrain with foliage (Geometry B), at the one kilometer distance the path attenuation varies from a 87 dB at 47.2 MHz to 199 dB at 3400 MHz In mountainous terrain (Geometry D), at the one kilometer distance the path attenuation varies from 94 dB at 47.2 MHz to 18 1 dB at 3400 MHz. Thus, for the example transmitter power and receiver sensitivity, the Geometry B and D results indicate that only the 47 MHz and 425 MHZ frequency bands could reliably support a one kilometer communication link in non-LOS conditions. Geometry D further indicates that none of the frequency bands will provide a link that is totally immune from dropouts in all conditions.

3.6. FREQUENCY SELECTION CONCLUSIONS

There are three IVSAWS transmitter deployments — mobile, deployable, and fixed Frequencies below 500 MHZ appear useable in all three deployment cases whereas frquencies above 500 MHz do not appear useable in all three deployment cases. ‘Frequencies above 500 MHz do not appear useable in the case of mobile transmitter to passenger vehicle communication unless greater than 36 dBm EIRP is permitted. Frequencies above 500 MHz do appear feasible for fixed transmitters provided that the transmitters were positioned such that nearly LOS could be maintained over the area of intended coverage.

Hence, based on link losses alone, a below 500 MHz band is recommended if the same frequency band must provide links for all three IVSAWS transmitter deployments. However, splitting the communication among two bands based on deployment is an option if a “high” band is used for fixed sites and a “low” band is used for other deployments. Due to its many implications for the system’s communication architecture and hardware, a dual frequency band approach is strongly discouraged.

For two reasons, pursuing a combined IVHS and IVSAWS solution is not viable at this time. First, none of the frequency bands below 1 GHz have the minimum 25 MHz of bandwidth. Above 1 GHz, free space path losses become problematic. Large and expensive power amplifiers would be required to provide adequate connectivity. Second, frequencies above 1 GHz do not fit the automobile industries’plans to develop an integrated multi-band digital vehicle receiver. Above 1 GHz, the high component and antenna costs are not justifiable because services useful to the *driver* do not currently exist above this threshold Therefore, support for bands in the 100 KHz (AM radio) to 900 MHz (cellu1a.r phone) is more probable.

In lieu of a high end UHF band, the only option for a combined IVHS and IVSAWS solution is to target a currently occupied sub 1 GHz band for acquisition or co-channel use. The political and legal resistance that will be encountered in doing such should not be underestimated. Strong public, industry and political support will be needed to clear or co-occupy a channel. However, if IVHS is something the public truly wants, demand will dictate spectrum availability.

Any of the identified bands would be suitable for a proof-of-concept IVSAWS demonstration. However, three reasons favor selecting the FCC Part 15 902 MHz to 928 MHz band for the communications subsystem demons&on in IVSAWS Task D. First, commercial off the shelf spread spectrum communication equipment is not available in the other bands. The numerous commercial spread spectrum transmitter-receivers that exist for the Part 15 band will significantly decrease contract material costs with respect to developing or modifying hardware for use in the identified bands. Second, the 902 - 928 MHz band has nearly identical RF propagation with respect to the 901- 902 MHz, 930 - 931 MHz, and.940 - 941 MHz bands. Test results obtained using 902 - 928 radios will be directly applicable to radios operating in the other 900 MHz bands. Third, the 902 - 928 MHz band is at least as stressful as the other bands. Numerous industrial, scientific, and Medical (ISM) users, Part 15 devices, and other licensed systems occupy this band. Thus, results from the field will not be favorably skewed.

The 420 MHz to 450 MHz frequency band and the 450 MHz to 470 MHz frequency band are the most favorable from a nation-wide allocation point of view. The 42 MHz to 47 MHz Highway Maintenance band also seems feasible. These three bands are the three, non-prioritized recommendations for the frequency band of a final rather than demonstration IVSAWS.

The contents of the 410 MHz to 470 MHz frequency bands are shown in Figure 3.6. The 420 MHz to 450 MHz band contains four military radars, the Coastal Ranging System, and a 444 MHz Amateur Radio repeater. Of the radar and ranging systems, only the Pave Paws radar affects the inland continental United States. The four sites of AN/FPS-115 Pave Paws radars are shown in Figure 3.7. Thus, a 5 MHz allocation in the lower portion of the band away from the Amateur radio repeater seems promising.

Test results from a Part 15 frequency band will be somewhat skewed relative to the 420 MHz to 450 MHz frequency band. More representative results could be obtained by using a derivative of the PLRS transmitter receiver to peform the IVSAWS communication demonstration. A further benefit is that ranging algorithms are already part of PLRS. Such an approach would require a modification to the existing contract.

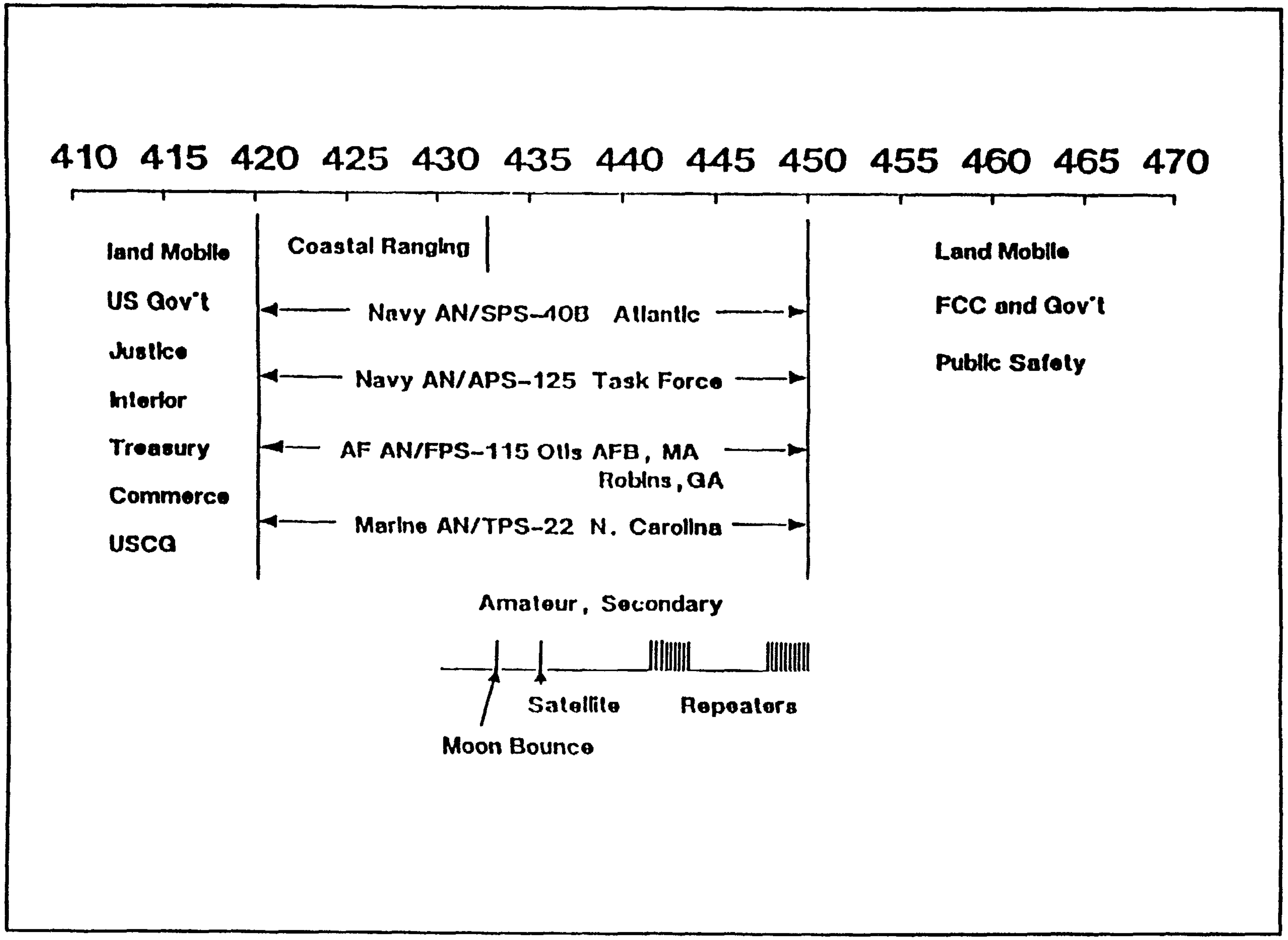

Figure 3.6. United States Frequency Usage in 410 MHz to 470 MHz Band.

[FHWA I-26]

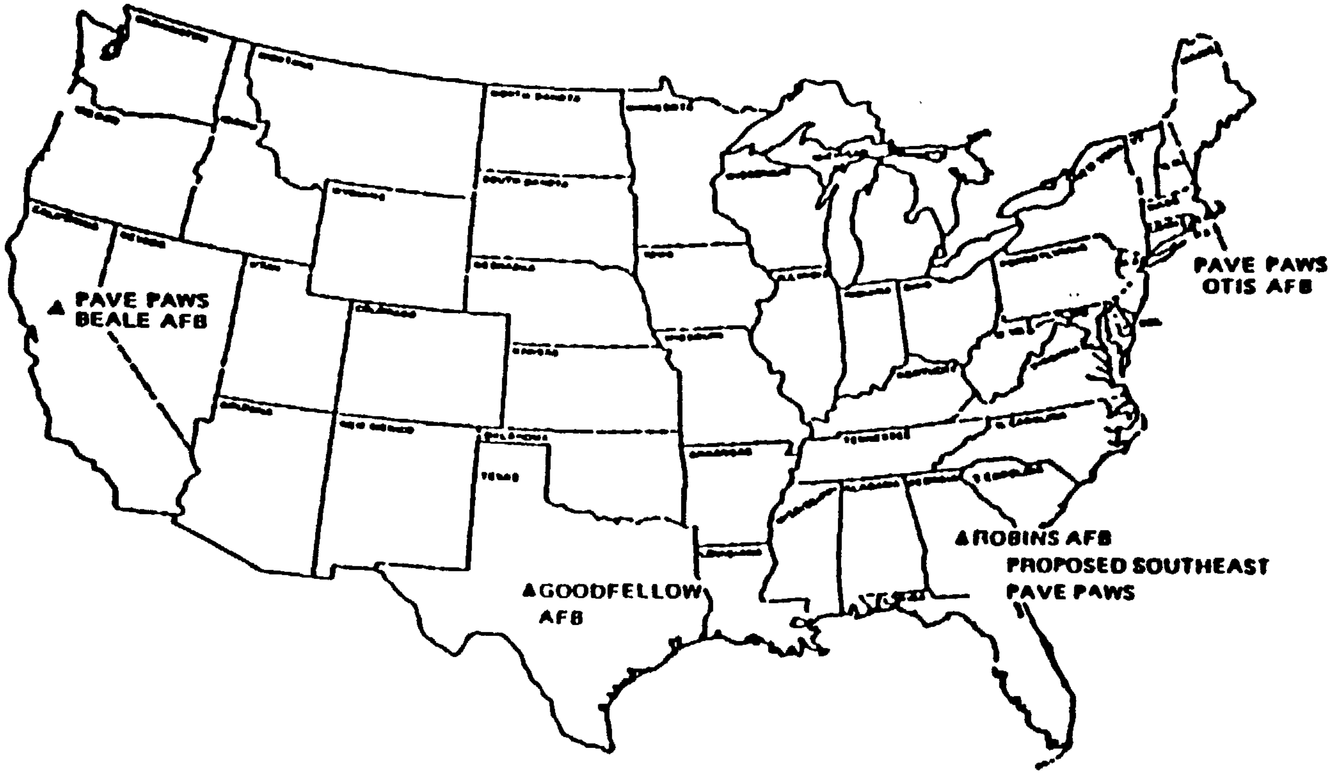

Figure 3.7. Site Locations of AN/FPS-115 PAVE PAWS.

4.0 RANGE DETERMINATION

4.1 OVERVIEW

The Driver Alert Distance (DAD) is the distance from a hazard that a driver must be warned so that the driver can perceive the situation and respond accordingly. The IVSAWS report showed that the DAD exceeds the distance at which the hazard fist enters the driver's field of vision [1]. As shown in Figure 4.1, the DAD is composed of a warning generation time, a warning effectiveness period (WEP), and a Decision Sight Distance (DSD). The DSD is defined as the distance travelled during the period of time required for a driver to detect and recognize a hazard (from the time the hazard first enters the driver's field of vision), decide upon a hazard avoidance response, initiate the response, and perform the maneuver. The time required and hence distance covered depends on the type of maneuver and the type of vehicle. The three types of maneuvers are designated increased attention, a lane change, and a full stop. The IVSAWS report also tabulated preliminary results for the time required to perform a corrective lane change. The two types of vehicles considered are passenger vehicles and commercial trucks. Combining the various factors yields an overall distance which is then the IVSAWS communication range.

4.2 ASSUMPTIONS

Prior to the Task B results, the communication range for a worse case hazard scenario was developed. The worse case scenario involves a high speed emergency vehicle approaching a high speed commercial truck Each vehicle is traveling at 80 mph. The emergency vehicle has a IVSAWS warning unit and the commercial truck has an IVSAWS vehicle unit. Furthermore, the truck must come to a full stop on wet payment with nearly bald tires. Under these conditions, the required communication range was 2.7 kilometers. Upon completion of the Task B report, using this worse case scenario as a valid design point has been re-evaluated.

The converging high speed vehicles is not an appropriate design point due to its statistical insignificance. The hazardous situation analysis in Task B determined that less than 0.2% of all traffic accidents involve an emergency vehicle approaching another vehicle head-on. A system that provides coverage when both vehicles are travelling at 99th percentile speed requires twice the communication range as a system that provides coverage for all other roadway hazards. The significant increase in cost of an over-designed system will render IVSAWS unaffordable.

STEP	TIME	VEHICLE ACTIONS	DRIVER ACTIONS	IVSAWS UNIT	HUMAN FACTORS
1	t_0	Vehicle approaches hazard	Driver uses normal driving skills	No Action. Signal not yet detected	
2	t_0			Signal detected Signal analyzed Warning selected	
3	t_1			Warning generated by visual and aural synthesizers	
4	t_2		Driver detects warning signal		
5	t_3		Driver understands warning		
6	t_4		Driver decides warning response		WARNING EFFECTIVENESS PERIOD
7	t_5		Driver begins warning response		
8	t_6	Vehicle in sight of hazard			DRIVER ALERT DISTANCE TIME
9	t_7		Driver detects hazard		
10	t_8		Driver recognizes hazard		
11	t_9		Driver decides hazard avoidance response		DECISION SIGHT DISTANCE TIME
12	t_{10}		Driver begins hazard avoidance response		
13	t_{11}	Vehicle avoids hazard	Driver continues normal driving		

Figure 4.1. Driver Alert Distance timeline.

The hazardous situation selected as the design point involves a receiver-quipped commercial truck or car approaching a stationary transmitter. Margin will be added to the calculated DSD in order to compensate for scenarios involving mobile transmitters approaching at modest speeds. DSD will be evaluated for vehicle speeds of 40,50,60,70 and 80 miles per hour. Eighty miles per hour the 98th percentile speed for interstate and rural arterial highways based upon measurements made by Olsen, et al. [2] DSD will be evaluated for three hazard avoidance maneuvers — complete stop prior to reaching hazard, lane change, and increased driver attention.

4.3 DSD EVALUATION

The DSD time can be sub-divided into two intervals: 1) the perception-response time and 2) the hazard avoidance maneuver time. These two parameters are evaluated for the hazard avoidance maneuvers under consideration.

Perception response time are determined through experimentation. Subjects perform hazard avoidance maneuvers in response to simulated roadway hazards and the elapsed time is measured. Current literature from these experiments specify the perception-response time to be 1.6 seconds. [3,4] However, much literature exists on the topic of perception-response times and estimates of a design value range *from* 0.9 second to 4 seconds, depending on road geometry and author opinion. The American Association of State Highway and Transportation Officials (AASHTO) recommends a design value of 2.5 seconds. [5] Because the purpose of the NSAWS study is not an exhaustive study of driver perception and reaction, the 2.5 second value has been selected as a baseline for the evaluation of DSD and DAD.

Hazard avoidance distances for the three maneuvers outlined above are listed in Table 4.1 for vehicle speeds of 40,50,60,70 and 80 miles per hour. Increased driver attention requires no vehicle maneuver and is assumed to be instantaneous upon driver perception of the hazard The braking maneuver is assumed to be a controlled stop on worn tires (2/32 inch tread) *over* a wet paved surface without wheel lock up.

Table 4.1 Hazard Avoidance Maneuver Distances

Vehicle Speed (mph)	Maneuver Distance (feet): Increased Attention	Lane Change[6]	Full Stop[7]: car	Heavy truck
40	0	260	220	380
50	0	300	380	650
60	0	340	620	990
70	0	380	940	1410
80	0	420	1370	1890

The DSD estimates are obtained by adding the 2.5 second perception-response time to the hazard avoidance maneuver distances in Table 4.1. The additional elapsed time for the perception-response translates into additional distance as a function of vehicle speed The resulting DSD are shown in Table 4.2.

Table 4.2 Decision Sight Distances

Vehicle Speed (mph)	Perception Response Distance (feet)	Decision Sight Distance (feet): Increased Attention	Lane Change	Full Stop: Car	Heavy ruck
40	150	150	410	370	530
50	180	180	480	560	825
60	220	220	560	840	1210
70	260	260	640	1200	1670
80	290	290	710	1560	2180

4.4 WARNING EFFECTIVENESS PERIOD (WEP)

In order for an IVSAWS waming to be effective the driver should understand the warning and be attentive to the impending hazard prior to the DSD. However, the driver should not be alerted so early that he or she disregards or forgets the warning before the hazard presents itself. Thus, the WFP is the period of time during which a driver can initiate a warning response (e.g., increased attention, removal of foot from accelerator) that will increase the probability of a successful hazard avoidance maneuver.

The time of the WEP can be estimated by considering traffic light operation. If it is assumed that the WEP for in-vehicle and roadway electronic warnings are similar, then the duration of the amber phase of traffic signals might be usable as a baseline for IVSAWS warning effectiveness. Olsen and Rothery [8] show that an amber period of 6 seconds is appropriate to warn drivers of an impending red light for vehicles travelling less than 50 miles per hour. Extending their analysis to vehicle speeds of 80 miles per hour yields a amber duration of slightly over 6 seconds.

The analogy between amber phase duration and IVSAWS WEP may not be entirely appropriate for two conflicting masons. The amber period includes time for a full stop prior to the intersection, which is the most stringent of the hazard avoidance maneuvers. Because hazard avoidance is not pan of the IVSAWS WEP, the amber period seems to over estimate the duration of the WEP. On the other hand, extending the amber phase beyond 6 seconds may not result in an ineffective warning although it is a popular hypothesis that drivers treat an extension of the amber beyond what is normally needed as an extension of the green. Thus, the IVSAWS WEP may be shorter or longer in duration than the 6 second amber phase duration.

Nevertheless, a 6 second IVSAWS WEP seems like a reasonable initial estimate to be verified or corrected during the subject testing phase of the study when considering the sparse nature of literature about warning effectiveness periods for electronically generated in-vehicle warnings.. Given this estimate, the IVSAWS warning units must repeat their broadcasts at least once every six seconds to ensure that drivers respond to IVSAWS warnings in a timely manner.

4.5 Driver Alert Distance (DAD)

The driver alert distance is composed of 1) the DSD, 2) the distance travelled during the WEP, and 3) the distance travelled by the vehicle from the point of message reception by the in-vehicle IVSAWS receiver up to driver comprehension of the warning. The latter two DAD intervals may or may not bc mutually exclusive, depending upon the point of message reception relative to the location of the roadway hazard

In the worst case the start of the WEP and the driver notification are simultaneous. Thus the hazard warning will be received, processed, and presented to the driver such that a warning response is initiated at the very beginning of the WEP. This requires that distance be built into the DAD to cover message processing by the in-vehicle receiver, warning generation, and driver detection and recognition of the warning (steps 10 though t4 Figure 4.1). Message processing will be nearly instantaneous. Message generation could take several seconds if speech synthesis is used. A two sentence English message could consume 5 seconds. Driver detection and perception of the hazard message is assumed (again, due to lack of relevant literature) to be equal to the 2.5 second hazard perception-response time described above. Table 4.3 lists the resulting Driver Alert Distance as a function of vehicle speed when each of these factors is accounted for.

Table 4.3 Driver Alert Distances

				Driver Alert Distance (feet)			
Vehicle speed (mph)	WEP distance (feet)	Message generation distance (feet)	Warning perception -response distance (feet)	Increased Attention	Lane Change	Full Stop Car	Full Stop Heavy truck
40	350	290	150	940	1200	1160	1320
50	440	370	180	1170	1470	1550	1815
60	530	440	220	1410	1750	2030	2400
70	620	520	260	1660	2040	2600	3070
80	710	590	290	1880	2300	3150	3770

The corresponding required IVSAWS communication range is 3770 feet (1150 meters) when vehicle and hazard are separated by a straight, flat road. As road curvature increases, the required communication range will decrease due to geometry.

4.6 LINK MARGINS IN TERRAIN GEOMETRIES

Four terrain geometries were selected as part of the process for recommending a frequency allocation for IVSAWS (Section 3). The geometries had to be typical of the United States and stressful in excess path loss. The selected geometries were: A) a straight, high speed highway over flat surface, B) a curved road with steep elevation through leafy trees, C) a highway through rolling hills, and D) a curved road with interleaving mountains. Other than total blockage by a mountain, the greatest excess path loss in the communication link is foliage attenuation. The IVSAWS communication system is design to complete the link under the worse case conditions of foliage loss, maximum range, 98th percentile speed, wet road, heavy vehicle, etc. Link margin exists whenever terrain geometry or hazard scenario are not worse case.

Figure 4.2 presents the link margins for the straight mad over flat surface (Geometry A) for various vehicle speeds and hazard avoidance maneuvers. The design has 30dB link margin under worse case hazard conditions for the straight road terrain geometry. Figure 4.3, Figure 4.4, and Figure 4.5 present the link margins for Geometry B, Geometry C, and Geometry D, respectively. Positive link margins are maintained in all cases except when dropouts occurs due to mountain peaks intersecting the line-of-sight between the roadway transmitter and vehicle (Scenario D), and when the required DAD requires the signal to propagate through more than 2000 feet of trees. With the specified design, transmitter-vehicle communication paths within the DAD with negative link margins will occur less than 1 percent of the time.

4.7 REFERENCES

[1] Federal Highway Administration, "Feasibility and Concept Selection of a Safety Hazard Advance Warning System (SHAWS) - Volume II - Technical, Report," Washington, D.C., Report No. FHWA/RD-81/124, April 1982, pp. 3-8,9.

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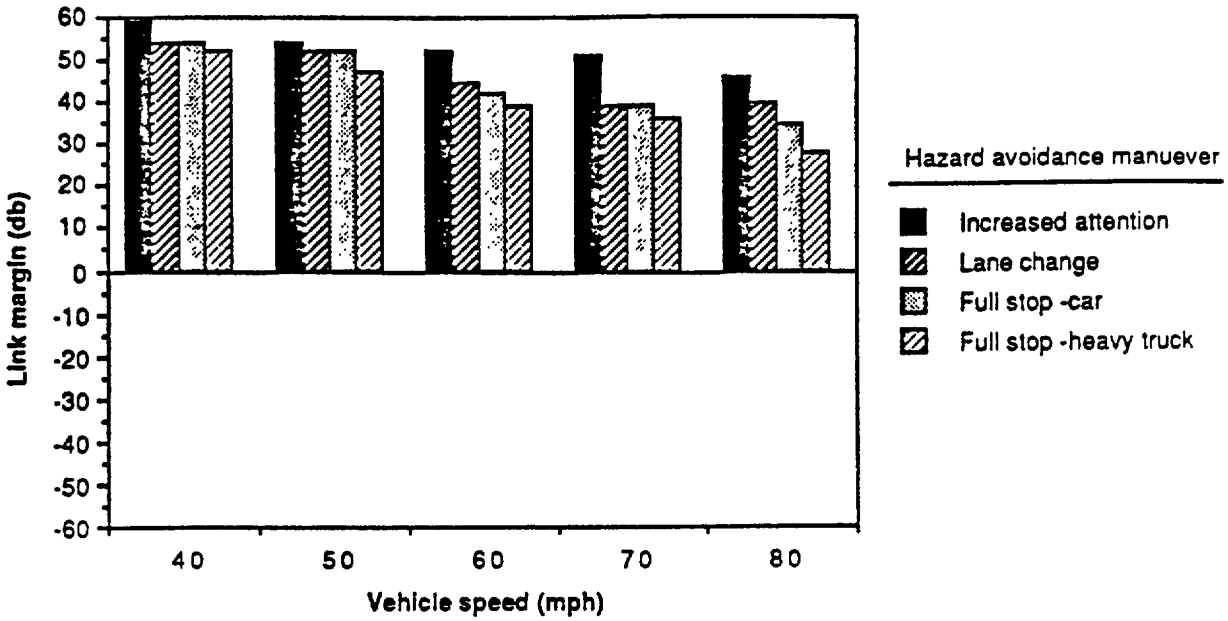


Figure 4.2. Geometry A link margins versus vehicle speed and hazard avoidance maneuver.

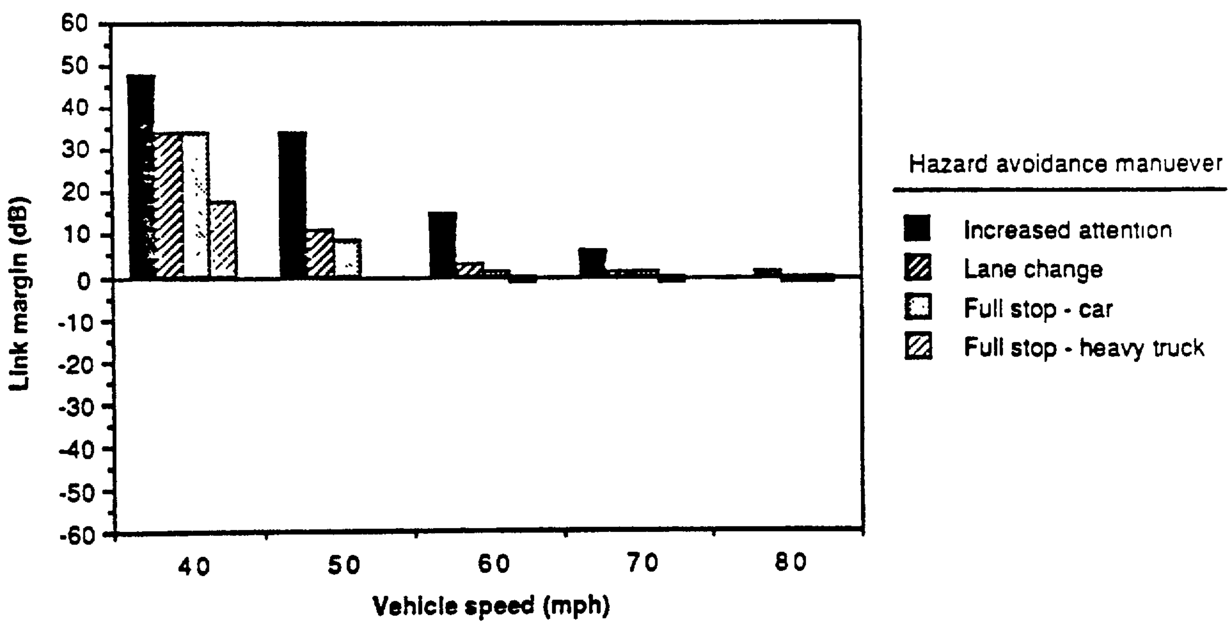


Figure 4.3. Geometry B link margins versus vehicle speed and hazard avoidance maneuver.

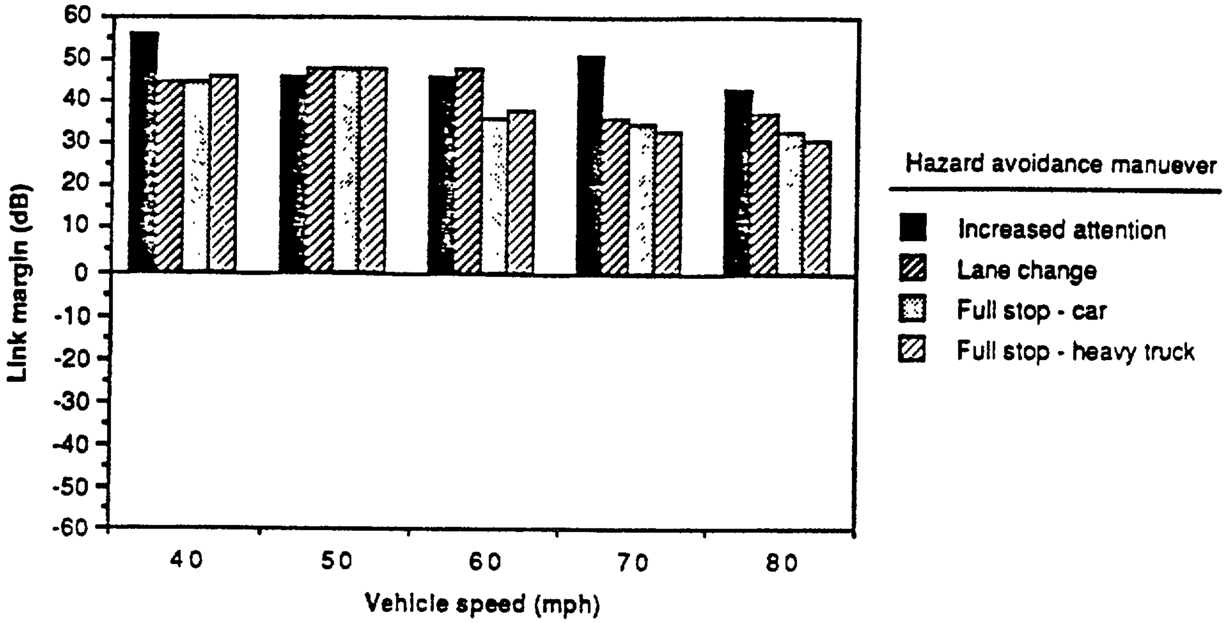


Figure 4.4. Geometry C link margins versus vehicle speed and hazard avoidance maneuver.

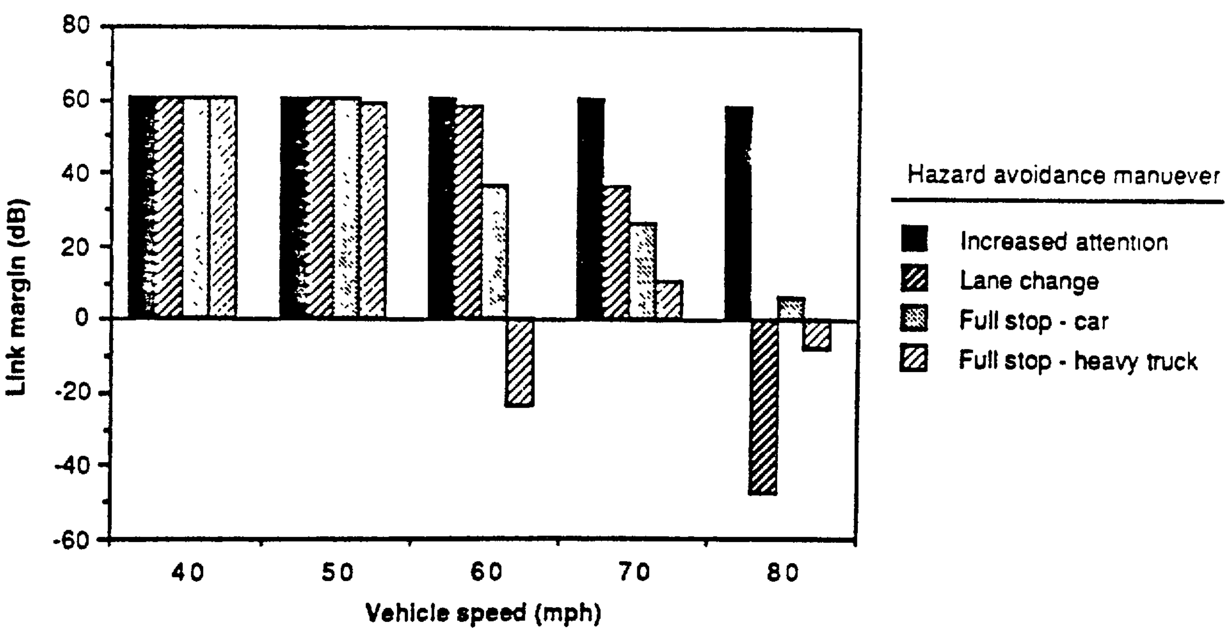


Figure 4.5. Geometry D link margins versus vehicle speed and hazard avoidance maneuver.

5.0 COMMUNICATION ARCHITECTURE SELECTION

5.1 OVERVIEW

IVSAWS consists of warning units and vehicle units linked together by a communication network. The warning units communicate safety and hazard warning to approaching vehicles quipped with IVSAWS units. IVSAWS is intended to ameliorate hazardous scenarios which have remained hazardous despite the application of traditional crash reduction treatments. In addition to transferring these warnings, the IVSAWS communication system design must also be responsive to cost and human factors issues. Cost considerations suggest that a simple broadcast network is the most appropriate communication architecture for IVSAWS. However, human factors considerations suggest that a more complicated duplex network is the most appropriate communication architecture for IVSAWS.

Given a two way communication architecture, the need to share congested communication resources and the need for high connectivity without dedicated links have lead to the development of multiple access network suuctures. Four different network suuctures are evaluated for IVSAWS. A slotted ALOHA protocol has been selected for IVSAWS. The evaluation includes a performance analysis of slotted ALOHA for the IVSAWS requirements.

5.2 CRITIQUE OF BROADCAST COMMUNICATION ARCHITECTURE

IVSAWS consists of warning units and vehicle units. The warning units communicate safety and hazard warning to approaching vehicles equipped with IVSAWS units. In addition to transferring these warnings, the IVSAWS communication system design must also be responsive to cost and human factors issues. Cost considerations suggest that a simple broadcast network is the desired communication architecture for IVSAWS. However, human factors considerations show that a broadcast network is an inadequate baseline design for IVSAWS.

IVSAWS alerts are supplemental safety information to motorists in rural and urban setting. Initially, IVSAWS will be an option on new passenger and commercial vehicles. The IVSAWS baseline design users the driver display system that is in or projected to be in every new vehicle. Eventually, IVSAWS will also be able as a retrofit kit for older passenger and commercial vehicles. The features provided by IVSAWS must be valuable to the consumer at an affordable price. Using an automobiles entertainment system as a guideline, the IVSAWS vehicle unit should cost about 100 dollars in order to be affordable to consumers. This low cost bogey suggests that the IVSAWS communication architecture should be a broadcast network. In a broadcast network, the IVSAWS units perform single functions as in an AM or FM radio network. A warning unit transmits the alert, the vehicle unit receives the alert, and the alert is immediately presented to the driver. A simple, low cost radio can satisfy the singular functions of each IVSAWS unit.

Having satisfied the cost objective, the broadcast network must be evaluated in the context of human factors issues. Section 4 of this report showed that hazard detection and hazard avoidance distance is a function of hazard type, vehicle type, and vehicle speed. For convenience, Table 4.3 is repeated here as Table 5.1. A commercial truck with 1/32 inch tire tread requires a minimum advance notice of 3770 feet (1150 meters) to come to a full stop from 80 mph on wet pavement. On the other hand, a passenger vehicle requires a minimum advance notice of only 940 feet (meters) to avoid roadside workers when traveling at 40 mph.

Table 5.1 Driver Alert Distances

				Driver Alert Distance (feet)			
Vehicle speed (mph)	WEP distance (feet)	Message generation distance (feet)	Warning perception -response distance (feet)	Increased Attention	Lane Change	Full Stop Car	Full Stop Heavy truck
40	350	290	150	940	1200	1160	1320
50	440	370	180	1170	1470	1550	1815
60	530	440	220	1410	1750	2030	2400
70	620	520	260	1660	2040	2600	3070
80	710	590	290	1880	2300	3150	3770

A broadcast system must provide adequate warning for the worse case hazard scenario. This worse case scenario includes maximum range, 98th percentile speed, heavy vehicle, wet pavement, and terrain geometry features such a foliage loss. The IVSAWS link budget under these conditions is given in Table 5.2. Link margin exists whenever the terrain geometry or hazard scenario are not worse case. Table 5.3 gives the excess link margin for a scenario of a emergency vehicle warning unit transmitting to a 40 mph passenger vehicle in flat open terrain (no foliage loss). This excess link margin translates into additional communication range. In a broadcast architecture, the additional communication range equates to excess time prior to the hazard that the driver receives notification.

Table 5.2 Link Budget for Worse Case Scenario

COMPONENT	VALUE	NET
Transmit Power	+ 36.0 dBm	+ 36.0 dBm
Tx Antenna Gain	0.0 dBI	+ 36.0 dBm
Tx Implementation Loss	- 2.0 dB	+ 34.0 dBm
Free Space Loss	- 86.1 dB	- 52.1 dBm
Foliage Attenuation (1km)	- 30.8 dB	- 82.9 dBm
Noise above Galactic	- 4.0 dB	- 86.9 dBm
Rx Antenna Gain	0.0 dBI	- 86.9 dBm
Rx Implementation Loss	- 2.0 dB	- 88.9 dBm
Rx Sensitivity	- 100.0 dBm	+ 11.1 dBm
Demodulation Threshold	11.1 dB	0.0 dBm

Table 5.3 Excess Link Margin for Minimal Scenario

COMPONENT	VALUE	NET
Transmit Power	+ 36.0 dBm	+ 36.0 dBm
Tx Antenna Gain	0.0 dBI	+ 36.0 dBm
Tx Implementation Loss	- 2.0 dB	+ 34.0 dBm
Free Space Loss	- 74.0 dB	- 40.0 dBm
Foliage Attenuation	0.0 dB	- 40.0 dBm
Noise above Galactic	- 4.0 dB	- 44.0 dBm
Rx Antenna Gain	0.0 dBI	- 44.0 dBm
Rx Implementation Loss	- 2.0 dB	- 46.0 dBm
Rx Sensitivity	- 100.0 dBm	+ 54.0 dBm
Demodulation Threshold	11.1 dB	+ 42.9 dBm

A broadcast system that provides notification for the worse case hazard and speed combination also provides premature warning whenever the conditions are not worse case. The impact of premature warning must be evaluated in human factors terms. If the notification is too early, then drivers may become confused and respond poorly or ignore the warnings. Repeated premature warnings coupled with occasional optimal warnings can lead to loss of driver confidence in IVSAWS. Similarly, repeated warnings so that the drivers do not forget or ignore premature warnings can lead to driver irritation. Drivers may respond to IVSAWS by simply disconnecting the system.

The 42.9 dB excess link margin can be converted to communication range by using the free space propagation loss equation.

$$L_P = (\lambda / 4\pi R)^2$$

The range R and wavelength λ must be in the same units. The free space propagation loss equation can be expressed in convenient frequency and range units.

$$L_{P\,dB} = 27.558 \text{ dB} - 20 \log f_{MHz} - 20 \log R_{meters}$$

The 42.9 dB excess link margin combined with the 74.05 range loss yields a maximum tolerable propagation loss of 116.95 dB. After removing the 27.558 dB factor for unit conversion and the 52.465 dB factor for 420 MHz, the range loss is 92.04 dB. This 92.04 dB range loss translates to 40 kilometers or 24.86 miles communication range in open flat terrain.

Comparing the two hazard scenarios shows that a vehicle traveling at 40 mph in open flat terrain may receive a IVSAWS alert 25 miles too early under a broadcast architecture. This vehicle would travel for 37 minutes after receiving the alert message before the driver actually encountered the hazard situation. Intuitively, this alert is excessively premature and defeats the intention of IVSAWS. More quantitatively, the Department of Transportation has commissioned several studies for the placement of toll booth signs to obtain proper driver reactions. These studies have concluded that the proper warning is 120 seconds from the toll booth at the corresponding vehicle speed. If the placement of the toll booth signs provided more than 120 seconds of warning, then the driver was likely to forget or in confusion perform maneuvers detrimental to the safety of other drivers. Because IVSAWS provides safety alerts and hazard warnings, excessively premature warnings are unacceptable in human factors terms. Therefore, although radio units for a broadcast network are guaranteed to meet the cost goals of the program, the human factors issues render a broadcast network as an inappropriate communication architecture for IVSAWS.

5.3 COMMUNICATION ARCHITECTURES WITH RANGE DETERMINATION

To overcome the premature warning problem, the IVSAWS vehicle unit needs to know the hazard type, the vehicle speed, and the range from the hazard. The hazard type can be included in the alert message from the warning unit, The vehicle speed can be obtained from the vehicle itself. However, the relative range information must be derived from position location data. Two different architectures will support relative range measurements, but only one of these architectures will meet the vehicle unit cost and reliability goals.

The first possibility is to include a Global Positioning System (GPS) receiver in both the warning unit and the vehicle unit. A GPS receiver gets timing transmissions from three satellites. Combining the timing information with ephemeris data stored in the receiver, the GPS unit can compute its absolute location in two dimensions. The commercial Clear Access C/A GPS channel has 25 meter accuracy. As part of the IVSAWS architecture, the warning unit would included its GPS position in the alert message. The vehicle unit then compares its GPS position with the warning unit GPS position to obtain the range between the vehicle unit and the warning unit The alert message would then be presented to the driver at the appropriate range.

This GPS approach has several complications at this time. Continuous satellite coverage is an issue. Prior to 1990, complete daily satellite coverage in the continental United States was not possible. In 1990 two additional GPS satellites were placed in orbit resulting in 24 hour coverage in the continental United States. However, the quality of coverage is questionable because all the GPS satellites will not be placed into orbit until 1993 at the earliest. Thus, the GPS satellites may be diverted at any time, such as during the Gulf War, to cover priority areas. Furthermore, without the full constellation, the precision is variable. The current aperiodic orbits of the satellites results in Geomeaic Dilution of Precision (GDOP). Finally, the Original Equipment Manufactures (OEM) prices for single channel GPS receiver cards exceed the 100 dollar cost objective of the IVSAWS program. For example, the Rockwell NavCore VGPS Receiver Engine is priced at 450 dollars. In IVSAWS this cost would be in addition to the cost of the IVSAWs communication link equipment. With the combination of these factors, GPS is not a viable approach to IVSAWS ranging.

The alternate ranging approach is based on cooperative two way communication. The range information is obtained by measuring the elapsed time between a message and its acknowledgement. Figure 5.1 illustrates this process. The ranging computation algorithm and the waveform to support the ranging process are proven technology from the Position Location and Reporting System (PLRS). PLRS was designed and manufactured by Hughes Aircraft Company for the United States Marine Corps. The ranging process uses a spread spectrum waveform. In addition to contributing to the range measurement, the spread spectrum waveform provides processing gain for immunity against noise and interference.

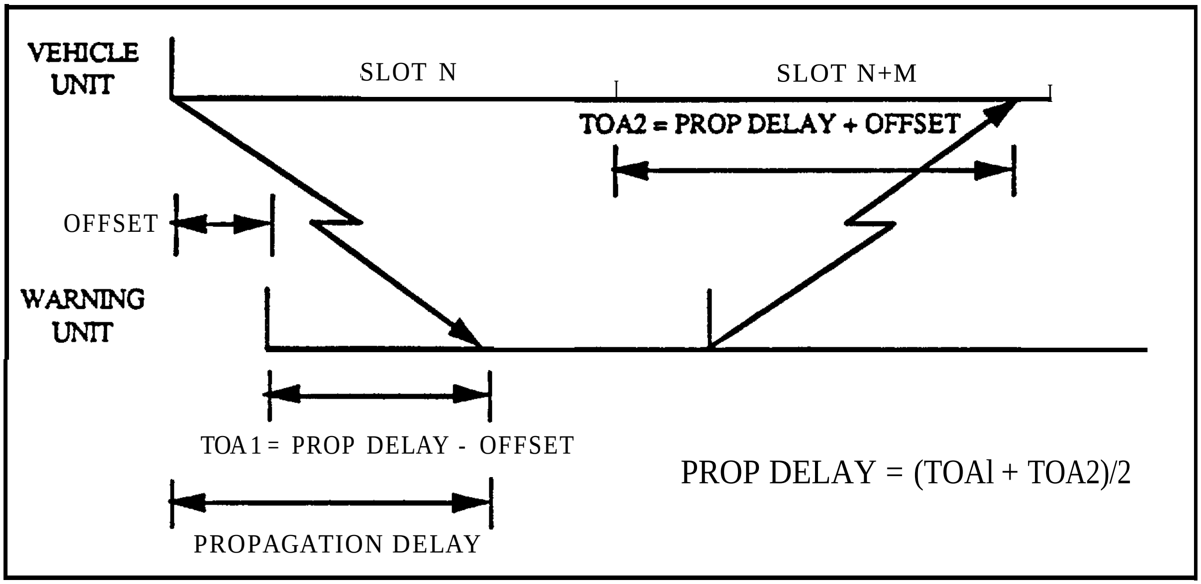


Figure 5.1. Ranging using Round Trip Timing Process.

The distance between two units can be obtained by measuring the propagation time for a message and its acknowledgement. A unit desiring range, in this case the IVSAWS vehicle unit, transmits a Round Trip Timing Interrogate (RTT-I) message. RTT-I is addressed to the warning unit and contains that vehicle unit identification. The warning unit measures the time of arrival (TOA) of the RTT-I. The warning unit responds to that specific vehicle unit by transmitting a RTT Response (RTT-R) message. The RTT-R includes the TOA measurement. The vehicle unit measures the TOA of the RTT-R. The vehicle unit computes the propagation time between it and the warning unit by averaging the TOA measurement. Prior to averaging, the TOA measurements are adjusted to account for processing delays in either unit. The elapsed time for the propagation is then converted to distance.

The range accuracy is a function of the chipping fate in the spread spectrum waveform and the number of clock phases that the early-late tracking circuitry can resolve. A 4.9152 MHz spread spectrum waveform has a chip duration of 203 nanoseconds. At 1 foot per nanosecond, the initial range estimate is accurate to 203 feet. As part of the demodulation process, the early-late tracking circuitry measures energy relative to the current chip analog to digital sampling point and adjusts the sampling point accordingly. The adjustments are some fraction of the fundamental chip time. To obtain these fractions, digital circuitry operating at a higher frequency clock is required. A 40 MHz clock frquency represents near state of the art for a VLSI digital implementation using CMOS technology. The low power consumption characteristic of CMOS digital circuitry is necessary for the IVSAWS implementation. All three deployments of the warning units will be battery powered and only the mobile deployment has access to constant battery recharging. The 40 MHz clock frequency limitation on a 5 MHz spread spectrum waveform represents an 8 times over-sampling. Thenfore, range can be resolved to l/8 of a chip time or 25.4 feet

Besides the range, to overcome the premature warning problem the IVSAWS vehicle unit needs to know the hazard type and the vehicle speed. The hazard type can be included in the aln message from the warning unit. The vehicle speed can be obtained from either of two methods. Fit, the IVSAWS unit can tap into the vehicle speedometer to obtain the vehicle speed. Second, the vehicle speed is calculated by performing a second range measurement The closing speed (range rate) is the relationship between the range difference and the elapsed time. The range rate method is the IVSAWS baseline. For new cars with electronic instrument panels, obtaining an electronic reading on the vehicle speed will be trivial. However, for older cars installing IVSAWS is a retrofit. The majority of older vehicles have mechanical rather than electronic dashboards. Separate installation kits with mechanical speedometer adapters for every vehicle model is an unrealistic logistic burden. A self contained IVSAWS is a more elegant design. Therefore, an IVSAWS vehicle unit obtains the host vehicle speed by performing multiple range calculations.

5.3 Network Structure Selection

Multiple access network structures were devised to satisfy two communication system needs. First, expensive communication channels must be shared in order to achieve efficient channel utilization. Second, a high degree of communication connectivity must be provided among independent subscribers without the burdensome cost of dedicated links between every pair of subscribers. Various protocols control subscriber access to the common channel so that the available bandwidth is allocated efficiently. The relative importance for a particular system of dynamic response, guaranteed service, or data throughput determines the overall measures of efficient channel utilization.

The IVSAWS network must accommodate potentially tens of thousands of warning units and millions of vehicle units. California alone has 17 million registered passenger and commercial vehicles. Although most drivers spend nearly their entire time in the same county or state, the IVSAWS network must accommodate the dynamics of cross country travel such as a vacation trip. These two requirements — number of users and system response time — rapidly determine the viable network structure for IVSAWS.

Four network structures — ALOHA, Polling, TDMA, and slotted ALOHA — were considered for IVSAWS. The ability of these networks to process large number of subscribers is summarized in Table 5.4. The ability of these networks to rapidly disseminate information and to handle rapid net entry and exit of new subscribers is also summarized in Table 5.4

Table 5.4 IVSAWS Network Structure Alternatives

, NETWORK ALTERNATIVES	NUMBER OF USERS	SYSTEM RESPONSE TIME
ALOHA	System crippled by many or high rate users.	Extremely dynamic. Fast user changes.
Polling / Reservation	Low throughput for large community.	Moderately dynamic. Slow user changes.
TDMA	Guaranteed throughput for large community.	Nationwide network. Rigid time reference.
Slotted ALOHA	Minimal delays for large community.	Very dynamic. Fast user changes.

ALOHA is a random access technique developed for computer networks. A subscriber with a message just transmits the message. As long as the majority of the messages are short and there is very little message traffic, probability favors that each message will get through without a collision. ALOHA is very dynamic as long as these criteria are met and crippled otherwise.

Polling and Reservation schemes are attempts to centrally conuol the channel to avoid collisions yet dynamically assign the channel so that message delays are minimal. For Polling or Reservation to function properly, the central controller must have knowledge of all subscribers or potential subscribers in the network. The polling and assignment process can totally consume network resources as the number of subscribers becomes large.

Time Division Multiple Access (TDMA) is a fixed channel assignment technique. The one is divided into fixed length intervals, called time slots, and then users are assigned particular time slots to transmit their messages. All users on the network must maintain exact time synchronization. TDMA guarantees a bounded response time for all users under extremely heavy loading conditions at the cost of a sophisticated, centralized network management scheme.

Slotted ALOHA is a hybrid structured contention scheme that combines the dynamic response to changes of the ALOHA protocol with the collision avoidance properties of time slots. In Slotted ALOHA, time is first divided into frames and then into time slots. Time slot lengths are tailored to the expected message length and number of messages. Every frame subscribers randomly select a time slot and then transmit their message. Probability again favors that each message will get through without a collision because the collision opportunities are discrete rather than continuous.

Of all the network structures considered, only ALOHA and slotted ALOHA protocols can handle to dynamic nature of new vehicle units constantly entering the communication zone of a warning unit furthermore only slotted ALOHA can systematically handle the potentially large numbers of vehicle units within a warning units communication zone. Hence, slotted ALOHA the most appropriate network structure for IVSAWS.

5.4 TIME SLOT STRUCTURE

In Slotted ALOHA, time is first divided into frames and then into time slots. The frame and time slot composition evolves from considering several factors. First, a frame boundary is denoted by some mechanism. Second, time slot lengths are tailored to the expected message lengths and number of messages. Third, round trip timing messages are exchanged within a protocol, Fourth, the frame structure must not create mutual interference between alert messages from two warning units within the same local.

The warning unit and vehicle unit exchange round trip timing messages so that the vehicle unit can compute range from ‘the warning unit The details of the alert message could be part of the RTT response. So the protocol options are that the process can start with the warning unit transmitting an alert message or the process can start with the vehicle unit using an RTT interrogate to wake up the warning unit Both options provide sufficient functionality but the options have significantly different power consumption requirements. Power consumption is a significant issue for the temporary and permanent deployments of the warning units.

Suppose that the warning unit must listen constantly for RTT interrogate messages. Using the CMOS circuitry in the PLRS units as a guideline, the IVSAWS warning unit would be expected to consume 120 milli-Amps seconds. On the other hand, while transmitting an alert message for 6.875 milliseconds at 4 Watts using a 12 volt battery, a warning unit consumes 2.29 milli-Amp seconds. Receive mode power consumption dominates transmit mode power consumption. Hence, power consumption considerations dictate that the warning unit initiate the process. If there aren't vehicle units in the alert area, such as in a remote railroad crossing, then the warning unit can go into a wait state. Power consumption in a wait state is significantly less than in a receive state. The frame structure design based on this protocol is shown in Figure 5.2.

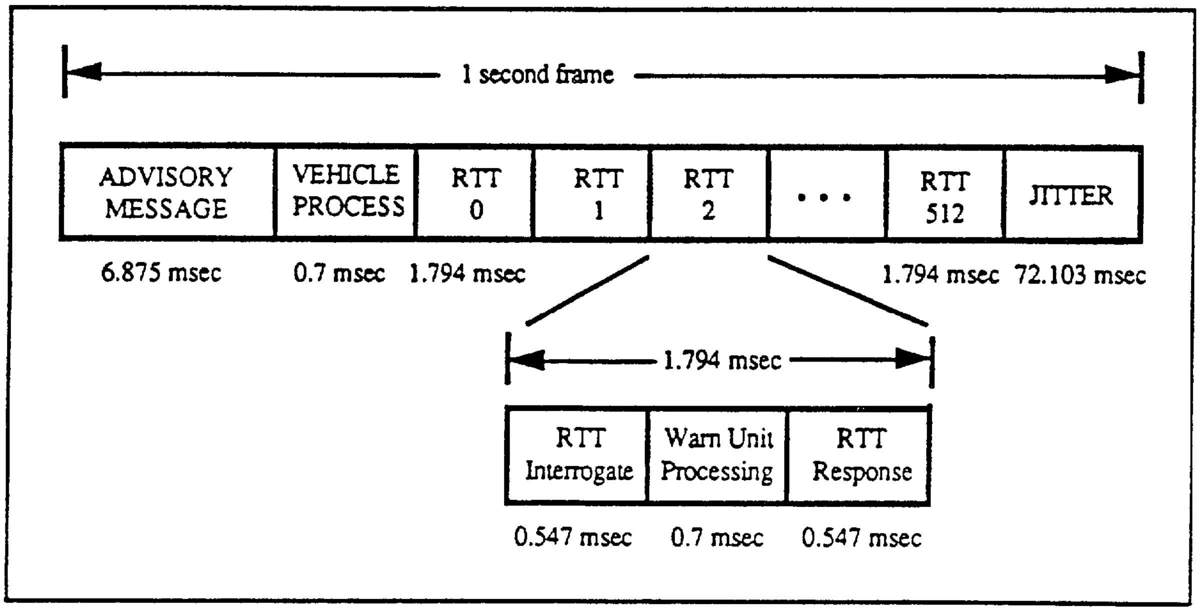


Figure 5.2. IVSAWS Slotted Aloha Structure.

Frame demarcations are relative to the warning unit. A frame begins when a warning unit transmits a hazard or advisory message. The message includes the warning unit's identification, hazard severity, and directional information. All vehicle units within communication range process this message. All vehicle units to which the directional information apply then transmit a RTT interrogate message in RTT slot 0. If only one vehicle unit responds in slot 0, then there isn't any contention, otherwise the strongest signal survives. The warning unit actions are based on whether or not it senses any transmissions in slot 0. If slot 0 does not contain any transmissions, then no vehicles are in the warning area or all vehicles have completed their ranging process, so the warning unit goes into a wait state to conserve power. If slot 0 contains a uansmission, then the warning unit provides a RTT response in the remainder of slot 0. The warning unit will listen for other RTT Interrogates during the remainder of the 1 second frame. Meanwhile, the vehicle units are selecting a random number between 1 and 5 12. Any vehicle which does not receive a RTT Response in slot 0 specifically addressed to it will attempt the ranging process again in the RTT slot corresponding to the random number selected.

Time slot lengths are tailored to the expected message lengths and number of messages. The initial alert slot is longer than the RTT slots. The alert message incorporates a flexible message structure so that IVSAWS have potential for growth and the means to be compatible with developments in IVHS. The alert message has 960 bits available for free text messages in addition to the bits required for message acquisition and unit identification. The RTT messages contain just enough bits for message acquisition and unit identification. The length of the RTT messages and the processing time determines the number of RTT slots that are available in a Came. The probability that two or more vehicle units will pick the same RTT slot is a function of the number of vehicles under steady state conditions and the number of RTT slots. The steady state conditions and the probability of collision are evaluated in Section 5.5.

The time slot includes a randomly selected jitter. The warning unit does not transmit its alert message exactly every 1 second. Suppose more than one warning unit were present at a site. For example, police, fire, and ambulances can all be present at an accident of a site where a permanent warning unit is also deployed. If every warning units clocks were aligned and if every unit transmitted exactly on the second boundary, then the warning units would interfere with each others transmissions. Instead, each warning unit randomly selects a jitter value with which to delay its transmissions. Jitter and spread spectrum processing gain will prevent the NSAWS link from experiencing mutual interference when multiple warning unit transmissions.

5.5 SLOTTED ALOHA PERFORMANCE

The warning unit performs the round trip timing process with all vehicle units within it communication range. The system loadings are quite different under initial conditions and steady state conditions. Initial conditions occur when the warning unit is first activated, potentially in an area already heavily congested with vehicles. Steady state conditions occur when the warning unit is responding to the normal ingress and egress of traffic, potentially at a multi-lane interstate with high-speed, closely spaced vehicles. Contention among the vehicle units responses are prevented in two ways. First, the warning unit has variable power settings. Second, the

IVSAWS communication network architecture is a variant of the slotted Aloha protocol.

The warning unit has adjustable transmission power settings up to the maximum 4 Watts transmission power. In the mobile and temporary deployments, the transmission power starts at the lowest setting and automatically increases gradually to the maximum power. When the warning unit is first activated, the initial transmission power is 2.25 dBm. Every 2 seconds after activation, the warning unit increases the transmitted power by 2.25 dBm until the maximum 36 dBm power is transmitted. Each time the power is increased, another subset of the vehicles within the maximum communication range are processed in an orderly fashion thereby minimizing contention. The maximum 36 d.Bm transmitter power quates to a 1 kilometer transmission range in dense foliage. In the permanent deployment, the transmission power can be set at the appropriate level for the given terrain conditions.

The worse case initial conditions were evaluated using a simulation of the slotted ALOHA protocol for IVSAWS. When the warning unit transmits at maximum power in open flat terrain, the communication range is 2 kilometers in all directions. So consider a 4 kilometer section of a dangerously congested highway. Assume 4 lanes of traffic in each direction and the vehicles are travelling at 85 mph with 1 second spacing. The result is 832 vehicles. Arbitrarily doubling this number produces a very loose upper bound of 2000 vehicles. The simulation results for 2000 vehicles are shown in Figure 5.3. Thus under exaggerated worse case initial conditions, the warning unit requires 8 seconds to work off the initial que of RTT messages. With the gradual increase in transmitter power rather than just maximum transmitted power, the warning unit will only require at most 1 second to work off the initial que of RTT messages.

The worse case steady state conditions were evaluated using a simulation of the slotted ALOHA protocol for IVSAWS. Again, when the warning unit transmits at maximum power in open flat terrain, the communication range is 2 kilometers in all directions. So consider a 4 kilometer section of a dangerously congested highway. Assume 4 lanes of traffic in each direction and the vehicles are travelling at 85 mph with 1 second spacing. The result is 8 vehicles per second ingressing and egressing from the communication region. The simulation modelled the vehicle arrivals as a Poison random arrival process of 0 to 32 vehicles with an average arrival rate of 8 vehicle per second. The steady state simulation results are shown in Figure 5.4. In steady state conditions, 99.9% of the vehicle units receive a response in the first frame and the remaining 0.1% get through on the second frame. Thus under exaggerated worse case steady state conditions, the warning unit can process the overwhelming majority RTT interrogates within the same frame that the RTT interrogates were transmitted.

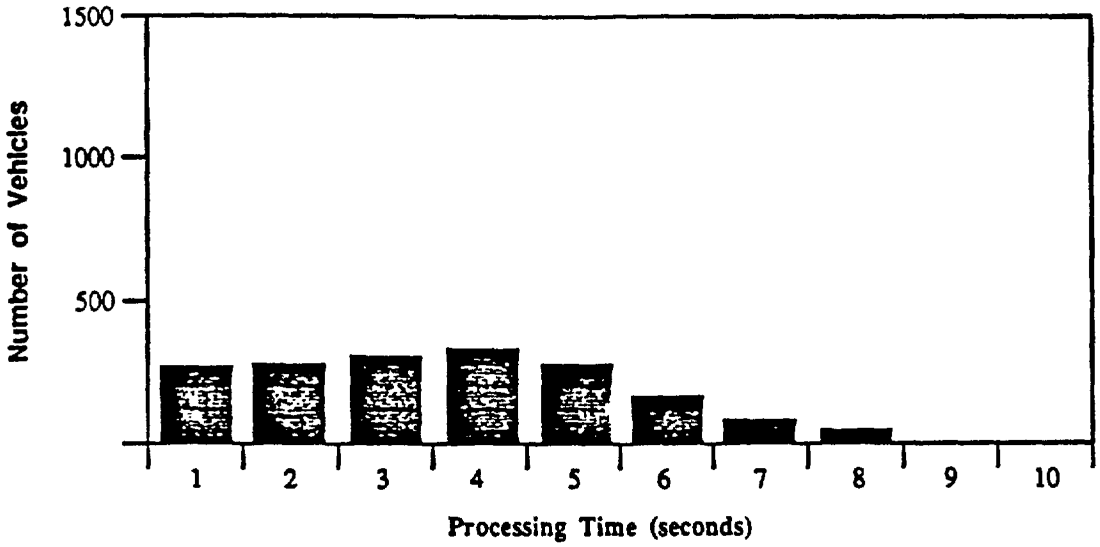


Figure 5.3. IVSAWS Slotted Aloha Performance for Worse Case Initial Conditions.

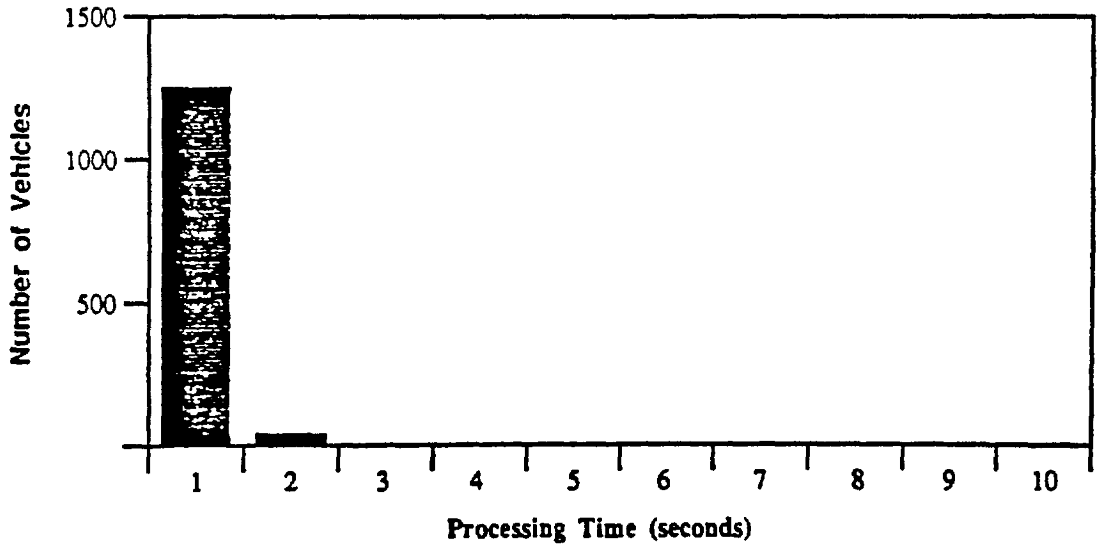


Figure 5.4. IVSAWS Slotted Aloha Performance for Worse Case Steady State Conditions.

In a slotted ALOHA protocol, contention is minimal when the number of times slots is large (> 5 times) compared to the number of active users. In the IVSAWS design, the number of time slots is 512 and the average number of active users is 16. The average number of active users is the 8 vehicle units first entering the communication area plus the 8 vehicle units performing their second RTT measurement to obtain vehicle speed. The probability that a collision occurs is the probability that two or more vehicle units select the same RTT time slot. Each RTT slot is equi-probable. The following equation gives the probability of collision.

$$\text{P(collision)} = \sum_{v=2}^{16} \left(\frac{1}{512}\right)^{v} \left(1 - \frac{1}{512}\right)^{16-v}$$

With a probability of collision equal to 0.000003718, under most circumstances all vehicle units pick a distinct time slot to initiate the RTT process. Hence, the warning unit can process all RTT interrogates within the same frame that the RTT process was initiated.

becomes complex or the direction of intended coverage becomes narrow, controlling the shape of the main beam will become more critical and rquire a larger and more costly antenna. It might be necessary to custom-build antennas for certain deployments, requiring a more skilled workforce to install and maintain transmitter sites. Sidelobes are also an issue. If a directive antenna is mounted on an overpass, it will be difficult to prevent message reception by vehicles travelling the underpass due to sidelobe splatter. Additionally, the antennas used to achieve a directive pattern tend to be rigid and large, and would thus become a more likely vandalism target than a less conspicuous and rugged omnidirectional antenna Any method which uses complex, large, or multiple source antennas (e.g., directional antennas, leaky cable, TACAN, two-lobe transmitter) will be difficult to apply to mobile and temporary IVSAWS transmitter platforms. For example, directive antennas have limited application to temporarily deployed transmitters since the geometry of the desired area of coverage can change significantly from deployment to deployment. In some cases an omni-directional pattern will be desired in order to alert all approaching vehicles; in others, limiting the dissemination of information will be needed. Thus, multiple antennas would be required to cover all possible deployments (assuming available real-estate on deployable transmitters prohibits a phased-array antenna) and those who set up temporary transmitter sites would need to be trained in antenna selection (e.g., beamwidth and sidelobe considerations).

The use of radio direction finding techniques at the in-vehicle IVSAWS unit is attractive in the sense that it is applicable to all three IVSAWS roadway unit (RU) platforms. If all directionality processing were remoted to the vehicle, a single omnidirectional antenna could be used on fixed, temporary, and mobile RUs. As the IVSAWS report describes,

> "The easiest pattern to achieve, of course, is the omnidirectional pattern... This is the pattern normally achieved by a whip antenna such as commonly found on automobiles and walkie talkies. Therefon, from a cost and simplicity standpoint, the omnidirectional pattern is far cheaper."

Unfortunately, three omni-directional antennas (for cost and aesthetic reasons the use of a rotating antenna mounted on top of a vehicle has been dismissed) are required in order to unambiguously determine the direction of signal arrival through differential time of arrival measurements. Automobile manufacturers art bound to resist implementation of such a scheme due to its "porcupine" effect on the appearance of a car. The cost of precision positioning of the antennas would be an additional deterrent. Accurate positioning would be required since the antennas must be mounted on a surface area (presumably the roof) which is small with respect to the area of coverage.

Inhibit tranmitters are only applicable to fixed and temporary hazard locations. Furthermore, if road geometry at a hazard becomes complex, three or more transmitters might be required (one, source, two or more inhibitors). For example, when approaching an intersection of two interstate highways up to twelve possible vehicle paths exist ("westbound" vehicles can choose to go straight, or switch to the "northbound" or "southbound" route of the other interstate, "northbound" vehicles can choose to go straight, or switch to the "eastbound" or "westbound" route of the other interstate, etc.). If only one of the interchanges between the two interstate highways was under reconstruction, it would be desirable to inform only those drivers travelling the interchange that they need to slow down and watch for construction personnel. Building an inhibitor deployment that could prevent message reception along the eleven other routes would be difficult at best

6.2.2 DIRECTION CONTROL USING A FLEXIBLE MESSAGE STRUCTURE

Figure 6-1a shows the framework of a flexible message structure that can be used to control the direction of coverage. The IVSAWS roadway units would be programmed (via a direction selection switch or download device) to limit the dissemination of hazard warnings to vehicles travelling in certain directions by setting the direction control field to match the specified directivity. By examining the content of the direction control field, in-vehicle IVSAWS units can filter useless hazard warnings provided they have knowledge of the vehicle's direction of travel. Orientation could by provided by a compass with a digital interface to the IVSAWS Communication Subsystem.

For example, in the overpass-underpass scenario, if the overpass spanned East (90 degrees) IO West (180 degrees) with respect to magnetic north, the Message Control Field could be made two layers deep and specify that vehicles with bearings ranging from 75o to 105o or 165o to 195o should process the hazard warning. The fields would be made wide enough to compensate for road curvature approaching the overpass and uncertainty in compass readings but not so wide that compass readings from vehicles travelling the underpass would fall within the specified ranges. Thus, as a vehicle approaches the overpass it will receive a hazard warning message, sample its compass, and check if the sampled reading falls within the specified ranges. Only those vehicles travelling the overpass will pass the check and pass the warning to the driver.

This approach allows the use of a single IVSAWS roadway unit with a rugged omnidirectional antenna to conuol message directivity. The basic architecture is applicable to all three RU platforms. Installation or setup is not critical since RU position or orientation does not impact effectiveness provided the antenna is not "hid" behind a large obstacle. The additional cost of a vehicle-based compass can be made small provided it is produced in large quantities. The same compass can be shared with other vehicle-based systems such as a driver navigation aide.

Although a vehicle will know it if is travelling in the right direction to process a message, it will not know if it is “upstream” or “downstream” of a hazard. Generally, this is not a problem, but false alarms are possible. In the overpass-underpass example, if a side road connects to the overpass route within communication range of the RU, a driver of a vehicle which turns on to the overpass route but then moves away from the bridge will be alerted even though his vehicle will never encounter the hazard, This false alarm can be eliminated if the in-vehicle IVSAWS unit can determine if the vehicle is approaching or moving away from the RU. A two-way ranging function built into IVSAWS can provide this capability. Still, road geometries exist in which a flexible message structure combined with ranging is insufficient to eliminate all false alarms. A mobile IVSAWS RU travelling a winding road is a case in point. If it is desired that the RU only inform drivers approaching the mobile hazard from behind (i.e., in the same direction of travel) the RU will necessarily update the Message Control Field based upon the direction the vehicle (hazard) is travelling. But on a winding road it is still possible that vehicles approaching the IVSAWS RU head-on will pass the ranging and directional criteria required and to pass the alert to the driver.

6.2.3 DIRECTION CONTROL SUMMARY

Table 6-l summarizes the range of application and relative effectiveness of the direction control options considered.

Table 6-1. COMPARISON OF DIRECTION CONTROL ALTERNATIVES.

Method	Application			Relative Effectiveness	Comments
	Fixed	Temporary	Mobile		
Directive Antenna	X	X	X	Fair	Antenna switching on Temp/mobile Rus probable. Controlling false alarms due to sidelobe splatter difficult.
Leaky Cable Antenna	X			Very Good	Very effective coverage control along curved and hilly roads.
Two Lobe Antenna	X	X	X	Moderate	Multiple transmitters required.
Inhibitor	X	X		Moderate	Multiple transmitters required.
Radio Direction Finder	X	X	X	Good	Complex in-vehicle IVSAWS antenna design required.
TACAN	X	X	X	Good	Complex RU antenna design required
Flexible Message Structure	X	X	X	Very Good	Two-way ranging required to minimize false alarms.

Of the alternatives considered, only the flexible message structure method implements an architecture which is transportable to all RU platforms while utilizing a single, inexpensive, and rugged antenna at both IVSAWS roadway and in-vehicle units. Ruggedness is a key issue. IVSAWS RUs at fixed sites are likely to become vandalism targets. Temporarily deployed RUs must withstand repeated assembly and disassembly. While the transceiver section can be enclosed in a housing, the antenna will always be exposed. When destroyed, it should be inexpensive to replace.

In order to minimize false alarms, a flexible message structure used for direction control should implement a ranging function. This requires a more sophisticated Communication Subsystem design than most of the alternatives considered. However, given the microelectronics technology advancements made during the 1980s. sophisticated systems can be made affordable when produced in quantiry. Ranging will not eliminate all false alarms. However, with a flexible message structure/ranging architecture, road geometries which possess poor false alarm characteristics should encompass a small percentage of the hazardous scenario population.

6.3 RANGE CONTROL

Range control is used (primarily) to ensure that an IVSAWS hazard warning is presented to the driver during the Warning Effectiveness Period. Table 4.3 shows that the Driver Alert Distance, the minimum distance in front of hazard that a driver should be warned by IVSAWS, is a function of vehicle speed and type of hazard. The IVHAWS report identifies five implementations which are potential candidates for controlling communication range:

- controlling transmitter power and/or receiver sensitivity
- placing low power transmitters “upstream” of a hazard
- the use of inhibit transmitters
- the use of transponders (two-way ranging)
- the use of a leaky cable antenna

Text from the IVSAWS report relevant to transmitter directivity is provided in Appendix C.

6.3.1 ANALYSIS OF SHAWS RANGE CONTROL ALTERNATIVES

The limitations of inhibit transmitters and leaky cable antennas were discussed in 6.2.1. In short, neither approach is applicable to all three RU deployment options. As road geometry becomes complex, the use of inhibitors becomes impractical. Likewise, for temporary deployments, the use of low power transmitters placed “upstream” of a hazard is a viable solution only if road geomeuy is simple. With this implementation, restricting the area of coverage to one lane of a two lane road would be difficult

Controlling transmitter power/receiver sensitivity and the use of transponders are the only options presented which can be applied to all three of the required RU platforms. In a non-homogeneous environment, setting the transmitter power or receiver sensitivity will result in some drivers receiving the IVSAWS warning too early or too late. Figure 6-2 depicts a transmitter deployed at an accident site along a curved road. In order to provide drivers from the North with adequate advance warning, the transmitter power will need to be set high enough to send a signal through the trees and be received at point A However, with this transmit power, the signal will be received by drivers approaching from the West before the Warning Effectiveness Period. Decreasing the transmit power such that Eastbound drivers receive the warning with the WEP will result in Southbound drivers receiving the warning too late.

The IVSAWS report dismisses the use of transponders (two-way ranging) for the following reasons:

- the cost is too high
- the architecture is easily overloaded
- insufficient bandwidth exist to support the architecture

Firstly, as described previously, with state-of-the-an microelectronics technology, a sophisticated IVSAWS with built-in ranging can be made affordable. Section 10 estimates the component cost of a ranging-capable system. The developmental cost, when distributed over a large number of units, will have negligible impact on the unit price. Secondly, Section 5 defines a communication (waveform) design which can support a large number of vehicles and provide a ranging capability. Thirdly, although this approach is bandwidth “hungry”, Section 3 identifies candidate bands which are wide enough to support a transponder architecture. Of the three issues, securing bandwidth will provide the largest obstacle to fielding a rangingcapable IVSAWS system.

6.3.2 RANGE CONTROL USING A FLEXIBLE MESSAGE STRUCTURE

Figure 6-lb shows the framework of a flexible message structure that, when combined with a ranging capability, can be used to control the area of coverage. As a IVSAWS-equipped vehicle approaches a hazard it will receive a hazard warning message and make a range measurement.

Based upon the type of hazard and vehicle speed it will calculate the Driver Alert Distance to the hazard. If the vehicle is within the WEP (again calculated as a function of vehicle speed), the warning will be presented to the driver. If the vehicle is well beyond the WEP, the warning w-ill be discarded If the vehicle is soon to enter the WEP, the Communication Subsystem will delay alerting the driver until the vehicle enters the WEP.

Approaching a school bus, the calculated DAD could be "small" in order avoid having the school bus turn onto an alternate route before the Decision Sight Distance. On the other hand, approaching an accident on an interstate, the calculated DAD could be made "large" to compensate for a potential back-up of vehicles behind accident site.

6.3.3 Direction Control Summary

Table 6-2 summarizes the range of application and relative effectiveness of the direction control options considered.

TABLE 6-2. COMPARISON OF RANGE CONTROL ALTERNATIVES.

Method	Application			Relative Effectiveness	Comments
	Fixed	Temporary	Mobile		
Transmitter Power/ Receiver Sensitivity Control	X	X	X	Poor	Hills and trees make control difficult.
Low Power Transmitters	X	X		Moderate	Multiple transmitters required.
Inhibitor	X	X		Moderate	Multiple transmitters required.
Leaky Cable	X			Very Good	Very effective along curved and hilly routes.
Flexible Message Structure with Ranging	X	X	X	Very Good	can compensate for vehicle speed and hazard type.

The use of a flexible message structure combined with a ranging capability is the only effective method applicable to fixed, temporary, and mobile IVSAWS RU sites. Since it can compensate for vehicle speed and hazard type, warning timing can be controlled such that IVSAWS hazard alerts will fall within the Warning Effectiveness period, even in non-homogeneous environments, No other alternative considered has this capability.

6.4 COVERAGE CONTROL IN AN IVHS ENVIRONMENT

Like IVSAWS a driver navigation aide (DNA) is a logical subsystem within an Intelligent Vehicle Highway System (IVHS). Thus when travelling intelligent highways, a vehicle should “know” the following: 1) which road it is on (e.g., US 1). 2) its position on the road (e.g., mile marker 136.95) and 3) in which direction it is travelling (e.g., North). This data could be displayed to the driver via a driver information center (DIC) in the form of a electronically generated map and vehicle marker shown on a CRT or LCD console. Regardless of the presentation and data source, the vehicle velocity (position and direction) can be made available to other IVHS subsystems, including IVSAWS through a common data bus, shared memory, or other interface. With this information, an IVSAWS implementation can be defined which uses a flexible message structure similar to those described in 6.2 and 6.3 to control coverage. The architecture would still use low cost and rugged omnidirectional antennas at the roadway units and on IVSAWS-equipped vehicles. The flexible message structure is applicable to all three transmitter deployment options and is described below.

Using a hypothetical scenario introduced above, information about a temporary hazard located on one interchange of an intersection of two interstate highways can be limited to vehicles travelling that interchange using a flexible message structure. Figure 6-1c shows the framework of a message structure that could be used to filter message presentation. In general, when an in-vehicle receiver captures a message transmitted by an IVSAWS RU, it will consult the DNA for the vehicle’s current position and direction (e.g. Interstate 10, West, mile marker 87.54). If this vector lies within the valid area of coverage as defined in the received message, the hazard warning message will be relayed to the driver via the DIC, otherwise it will be rejected The Valid Area of Coverage field within the IVSAWS message can be made several layers deep to provide coverage for those scenarios in which multiple highways need to be covered by a single IVSAWS RU.

Several forms of DNA-IVSAWS interface are possible based upon DNA system architecture. If the DNA receives frequent and high-resolution position updates from the highway-embedded DNA infrastructure, the DNA will know within a few yards of transition when the vehicle begins to travel the interchange. Up to this point in time the IVSAWS receiver rejects the periodic transmissions received from the temporarily deloyed RU since the position-direction vector it polls from the DNA is not sufficient to trigger display of the hazard warning message. When the

DNA is updated to reflect the change in course, the next transmission (or possibly a previous transmission if buffering is designed into the IVSAWS in-vehicle transceiver) will be processed and sent to the driver. A drawback to this DNA architecture is that if the hazard is located at the beginning of the interchange, the message may be presented to the driver inside of the Driver Alert Distance, that is, with insufficient advance warning. With a more advanced DNA subsystem this deficiency can be corrected if it "knows" in advance which highways a driver intends to use to reach his destination. In fact, the DNA should be capable of recommending a path and directing the driver via the DIC based upon destination data input by the driver prior to departure. With this architecture, less frequent position updates will be required if the DNA incorporates a deck-reckoning vehicle location function which continuously tracks the vehicle's position and direction in between updates. Now, as the vehicle approaches the interchange, the in-vehicle receiver will receive the hazard warning transmission from the IVSAWS RU and consult the DNA. Since the road segment defined by the Valid Area of Coverage field within the IVSAWS message is a member of recommended DNA route, the DNA will task itself to trigger the IVSAWS in-vehicle transceiver once the vehicle enters the Warning Effectiveness Period (WEP). When uiggered, the transceiver will send the hazard warning to the driver via the DIC with sufficient advance warning. However, even with a DNA, drivers will occasionally make wrong turns or deviate from the recommended path. Not far from the point of departure, the DNA will map a new recommended course. Even so, a driver may receive insufficient warning if a hazard is located close to the departure point from the recommended path.

6.5 COVERAGE CONTROL RECOMMENDATION

The most precise coverage control will be provided when IVSAWS is coupled to a Driver Navigation Aide as part of an Intelligent Vehicle Highway System. The fewest false alarms and missed alerts will occur with an IVSAWS-DNA architecture. However, since an intelligent highway will not be available during the concept demonstration phase of the IVSAWS program, a flexible message structure/two-way ranging architecture is recommended. Even as intelligent highways appear, their spread will be gradual and complete extension into the rural highway system might never occur. In the absence of intelligent highways, the proposed arvhitecture can provide accurate range and directional control for the vast majority of the rural and urban highway systems.

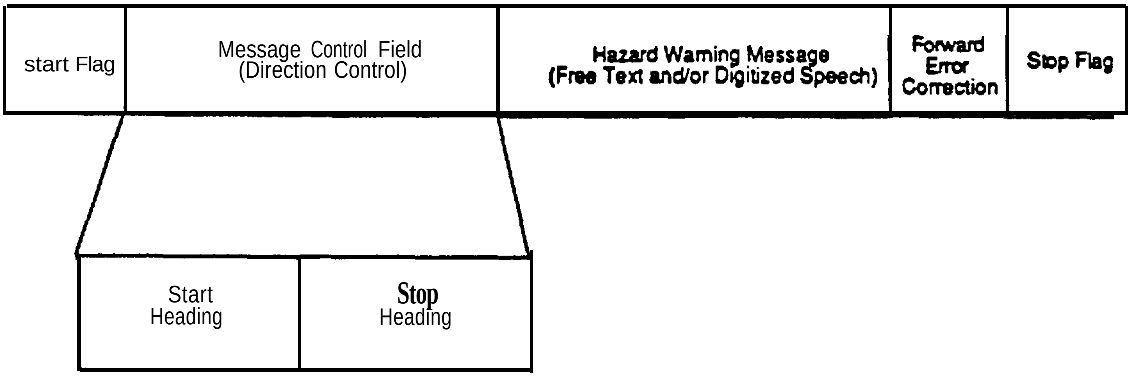


Figure 6-la. Direction Control Using a Flexible Message Structure.

Figure 6-1 b. Range Conuol Using a Flexible Message Structure.

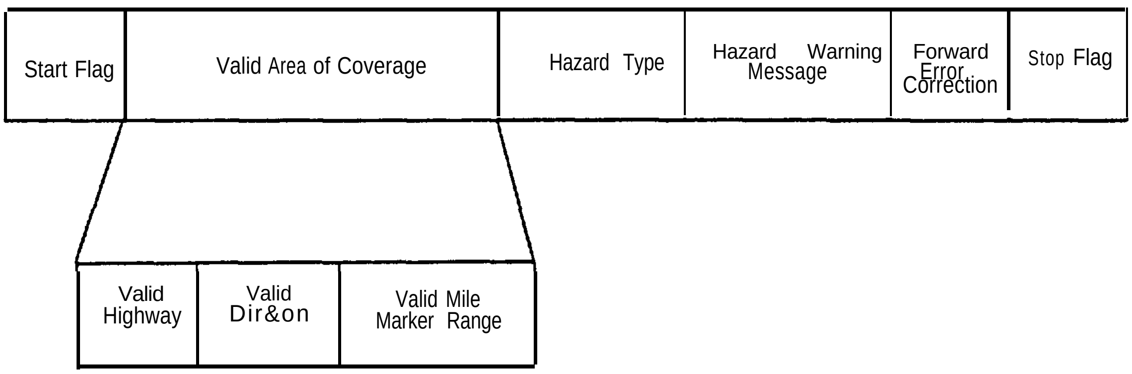


Figure 6- lc. Coverage Control Using a Flexible Message Structure in an IVHS Environment

Figure 6-1. Flexible Message Structure Frameworks.

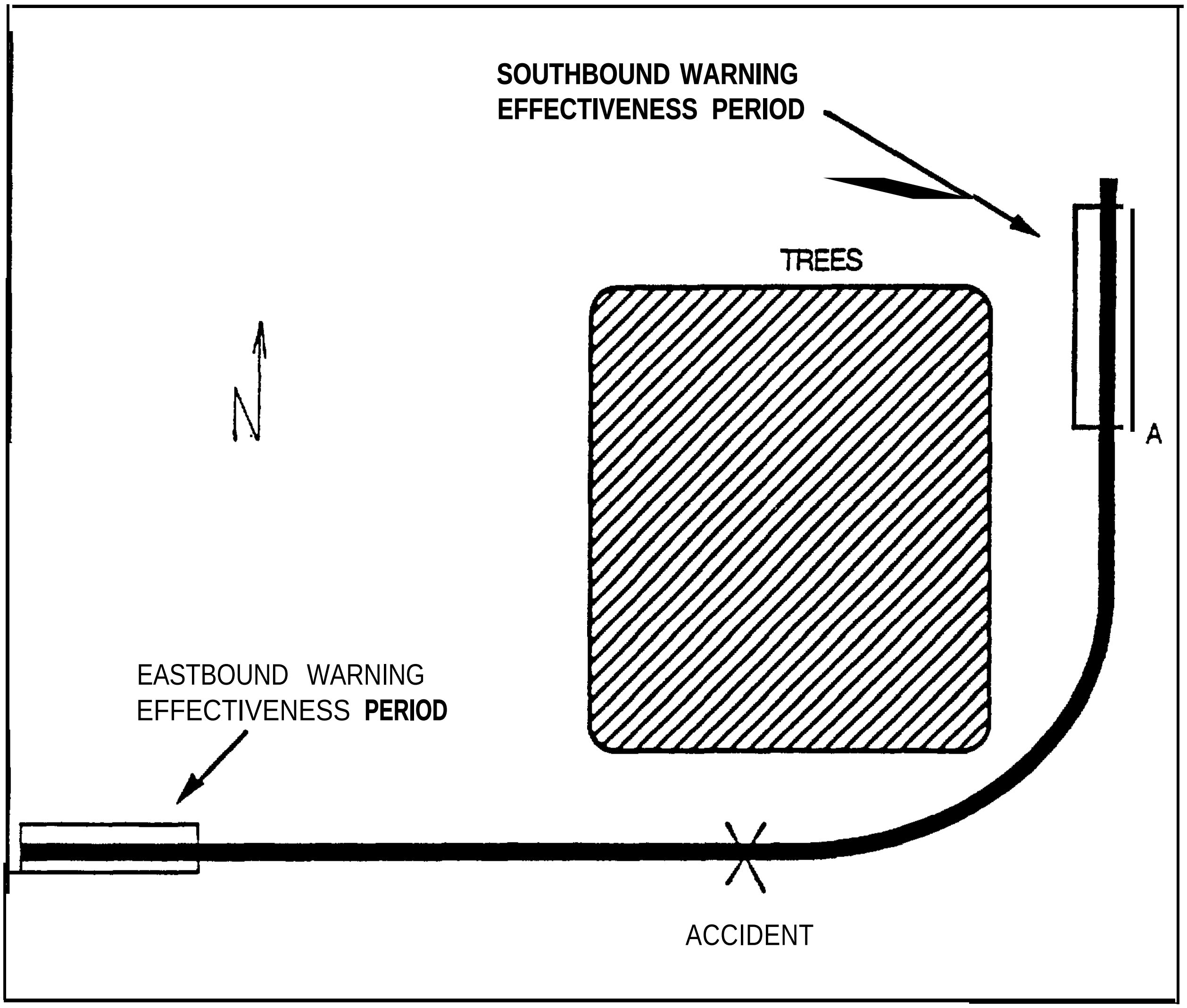


Figure 6-2. Non-homogeneous Communication Environment.

7.0 WAVEFORM DESIGN

7.1 OVERVIEW

The waveform design evolves by considering the channel characteristics, the system throughput requirements, and equipment cost goals. The relationships of these factors leads to the selection of a particular modulation scheme. Direct sequence spread spectrum techniques and forward error correction techniques are optional. A preambles is required to trigger message detection when transmissions are bursty rather than continuous. The iterative nature of waveform design is illustrated in Figure 7.1.

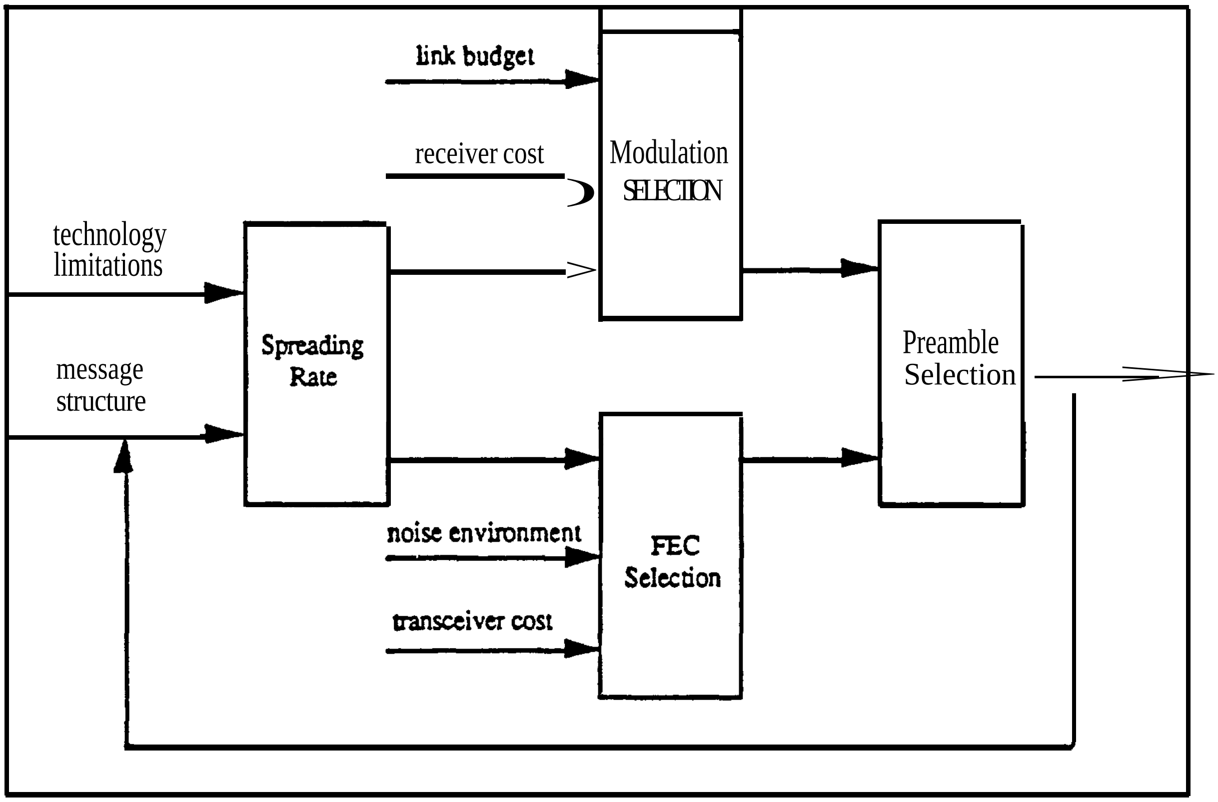


Figure 7.1. Task Flow for Waveform Design.

7.2 MESSAGE STRUCTURE

The communication link supports the ranging function and flexible message features of the system by using two types of messages. Both the r t t and Alert message types contain fields for preamble, time refine, system identification, and warning unit identification. The RTT message also contains a field for vehicle unit identification. The alert message also contains fields for hazard type, direction indicators, free text, and error detection. The bit allocations for each of these message types are given in Table 7. I and Table 72.

Table 7.1. Field Allocations for Alert Message

alert Message Field	Bits
Preamble	16
Time refine	8
System Type	8
Warning Unit Identification	16
Hazard Type & Various Flags	16
Direction Indicators	16
Free Text	960
Error Detection	16
Total	1056

Table 7.2. Field Allocations for RTT Message

RTT Message Field	Bits
Preamble	16
Time refine	8
System Type	8
Vehicle Unit Identification	36
Waming Unit Identification	16
Total	84

As a design philosophy, message fields were allocated in multiples of 8 bits whenever possible. Microcontrollers, such as the 6811 chosen for the IVSAWS radio implementation, have byte orientated processing. Software development is simpler and processing within the unit is faster when the field allocations match the processing capabilities of the microcontroller.

The IVSAWS transmissions are bursty rather than continuous like an AM or FM radio. Thus every message reception begins with a “message search”. The receiver continuously generates analog to digital samples of the ambient signal. The correlator circuit compares the 'data samples with the known preamble pattern. When the match is sufficiently close, the correlator declares a message detection and provides initial timing. The initial timing is refined during subsequent symbols so that the data can be demodulated properly. The correlator works on the principle of energy detection. The length of the preamble must provide sufficient energy so that the preamble is readily distinguishable from noise, The quality of the preamble is measured by the probability of detection and the probability of false alarm The performance of the IVSAWS preamble is discussed in Section 7.3 below.

The IVSAWS design has a flexible message structure. With a flexible message structure, IVSAWS can evolve as other IVHS come into existence. Furthermore, with a flexible message structure IVSAWS can be responsive to Department of Transportation studies that may identify new hazard situations within the purview of IVSAWS. The system type field is part of this flexibility. Messages that are specifically IVSAWS alerts will have one bit pattern in the system type field. Messages from other IVHS can be broadcast by the IVSAWS data link and so designated with a different bit pattern in the system type field The other significant component of the flexible message structure is the free text field The free text field allows the text of alert messages to be reprogrammed as the system evolves should the need arise. The 960 bits is enough space for 120 characters using 8 bit ASCII code or 160 characters using 6 bit ASCII code. The IVSAWS alerts must have sufficient length to provide adequate information yet be short enough to aid rapid driver comprehension and response.

Section 6 of this report discussed the various options for directional control in IVSAWS. The most viable approach is having directional indicators imbedded in the message structure. A separate bit is reserved for a sector. When the bit is set to one, then the alert message applies to vehicles travelling in that direction. With 8 bits, each sector is 45 degrees. With 16 bits, each sector is 22.5 degrees. The directional indicator field was assigned 16 bits due to the greater resolution. If the alert message should be omnidirectional in its coverage area, then all bits in the directional indicator field are set to one.

For unit identification, passenger vehicles may travel anywhere in the United States but warning units at best need to be regionally distinguished. The 36 bits in the vehicle unit identification corresponds to 68.72 billion vehicles. The 16 bits of the warning unit identification corresponds to 65,536 warning units.

Cyclic Redundancy Check (CRC) is a powerful error detection technique. CRC treats a data stream as a digital number and processes that number through a divider circuit Bit errors are detected because the results of the division process don't match at the transmitter and receiver. The detection capabilities of a CRC depends on the polynomial generator of the divider circuit Three international standards exist for a CRC generator:

CRC-12	x12+x11+x3+xz+x1+1
CRC-16	x16+x15+x2+1
CRC-CCITT	x16+x12+x5+1

These polynomial have been selected by the International Standards Organization (ISO) for providing the most error detection in the least amount of bits. IS0 is a voluntary, nontreaty organization whose members are the national standard organizations of the 89 member counties. Members include ANSI (U.S.), BSI (Great Britain), AFNOR (France). and DIN (Germany).

7.3 SPREAD SPECTRUM PROCESSING GAIN

A spread spectrum waveform provides immunity against noise and interference. Hence designs for digital communication systems try to incorporate as much spreading as possible. Technology costs present the upper limit on the spreading of the waveform. System data throughput presents the lower limit on the transmitted data rate. Combining these factors yields the amount of processing gain available to the system.

When a spread spectrum waveform is used to provide ranging, range accuracy depends on the waveform characteristics and the digital demodulation circuitry. The chipping rate in the spread spectrum waveform determines the initial accuracy of the range estimate. For a chip duration of T nanoseconds, the initial range estimate is accurate to T feet. This range estimate is refined to some fraction of T feet based on the over-sampling rate in the digital demodulator.

As part of the digital demodulation process, signal acquisition circuitry declares a chip boundary and then early-late tracking circuitry refine this estimate. The early-late tracking circuitry compares energy in the current analog to digital sampling point with energy in other analog to digital sampling points. Based on the measurements, the early-late sacking curcuitry adjusts the sampling point accordingly. The adjustments are some fraction of the fundamental chip time. To obtain these fractions, digital circuitry operating at a higher frequency is required. A 40 MHZ clock frequency represents near state of the art for a VLSI implementation using CMOS circuitry. The low power consumption characteristics of CMOS digital circuitry is necessary for the IVSAWS implementation. All three deployments of the warning units are battery powered and only the mobile deployment has access to constant battery recharging. To keep implementation losses for this portion to less than 1 dB, the over-sampling rate should not be less than 8 times. The 40 MHz clock frequency limitation and the at least 8 times over-sampling rate results in a maximum waveform spreading of 5 MHz for the IVSAWS application.

Within a frame, the minimum on-the-air data rate consists of 1 Alert message and 5 13 RTT message pairs without any allowances for processing time in the transmitters and receivers. The minimum on-the-air data rate is 87,240 bits per second — 1 message with 1056 bits and 1026 messages with 84 bits. Dividing the 5 MHz maximum waveform spreading by 872 Kbps minimum on-the-air data rate yields the maximum spreading of 57 chips per data bit. Powers of two are natural and low cost implementations for waveform spreading. The baseline design is 32 chips per bits of spreading because the design parameters won't permit a 64 chips per bit of spreading. The difference between 57 and 32 chips per bit is the time that can now be apportioned to processing function within the warning and vehicle units so that the IVSAWS design is realizable.

7.4 CANDIDATE WAVEFORMS

In a direct sequence spread spectum waveform, a pseudo random binary stram is modulated onto each data pulse. The higher rate binary data are called chips to distinguish them from the lower rate on the air binary data. For IVSAWS, the chip rate is 4.9152 MHz and the on-the-air data rate is 153.6 KHz. The 32 chip spreading provides 15 dB of immunity against noise and interference. The 32 chips per data bit can allocated by trading off forward error correction code (FEC) and modulation schemes. Binary Phase Shift Keying (BPSK) is a binaq, coherent modulation. Differential Phase Shift Keying (DPSK) is a binary, noncoherent modulation. The waveform candidates for IVSAWS are given in Table 7.3.

Table 7.3. Waveform Candidates

MODULATION	FIX
BPSK	Half rate
DPSK	Half rate
DPSK	None
256 ary	Inherent

A half rate FEC produces two coded data bits for every one uncoded data bit. If error correction is used in combination with binary modulation, each coded data bit is then spread by 16 chips to achieve the overall spreading rate of 32 chips per uncoded data bit. If error correction is not used in combination with binary modulation, each uncoded data bit is spread by 32 chips. In M-ary modulation, data bits arc grouped and the group determines the transmitted signal. Mary modulation produces a spreading of M divided by log2(M). A 32 chip spreading rate corresponds to a M = 256 signalling format. These issues are discussed in more detail below.

7.5 MODULATION ISSUES

In digital modulation, the information is contained in the phase angle of the signal not the amplitude of the signal. A digital zero is indicated by a 0 phase change in the carrier frequency. A digital one is indicated by a B phase change in the carrier frequency. If the receiver is locked to the transmitter's carrier frequency phase, then the signal is demodulated using coherent detection. If the receiver is not locked to the transmitter's carrier frequency phase, then the signal is demodulated using noncoherent detection. A coherent or noncoherent modulation is selected based on the relative system importance of power to complete the communication link versus receiver cost.

Coherent receivers require 1.5 dB less signal power than noncoherent receivers to correctly demodulate the signal. Figure 7.2 shows the bit error rate performance curves for Binary Phase Shift Keying, a coherent modulation, and Differential Phase Shift Keying, a noncoherent modulation.

On the other hand, coherent receivers require more complicated circuitry than noncoherent receivers to demodulate the signal. More complicated circuitry is required because the carrier is suppressed in digital modulation. For coherent demodulation, the receiver must first recover the carrier signal and then determine the carrier's phase. The carrier phase must be accurately tracked throughout the demodulation of the entire message. Carrier phase is tracked using a phase lock loop (PLL). PLL which have access to an unsuppressed carrier are simply called PLL. PLL which also recover the suppressed carrier are called Costas PLL. The block diagrams for a coherent and noncoherent receivers as shown in Figure 7.3 and Figure 7.4, respectively.

[FHWA I-66]

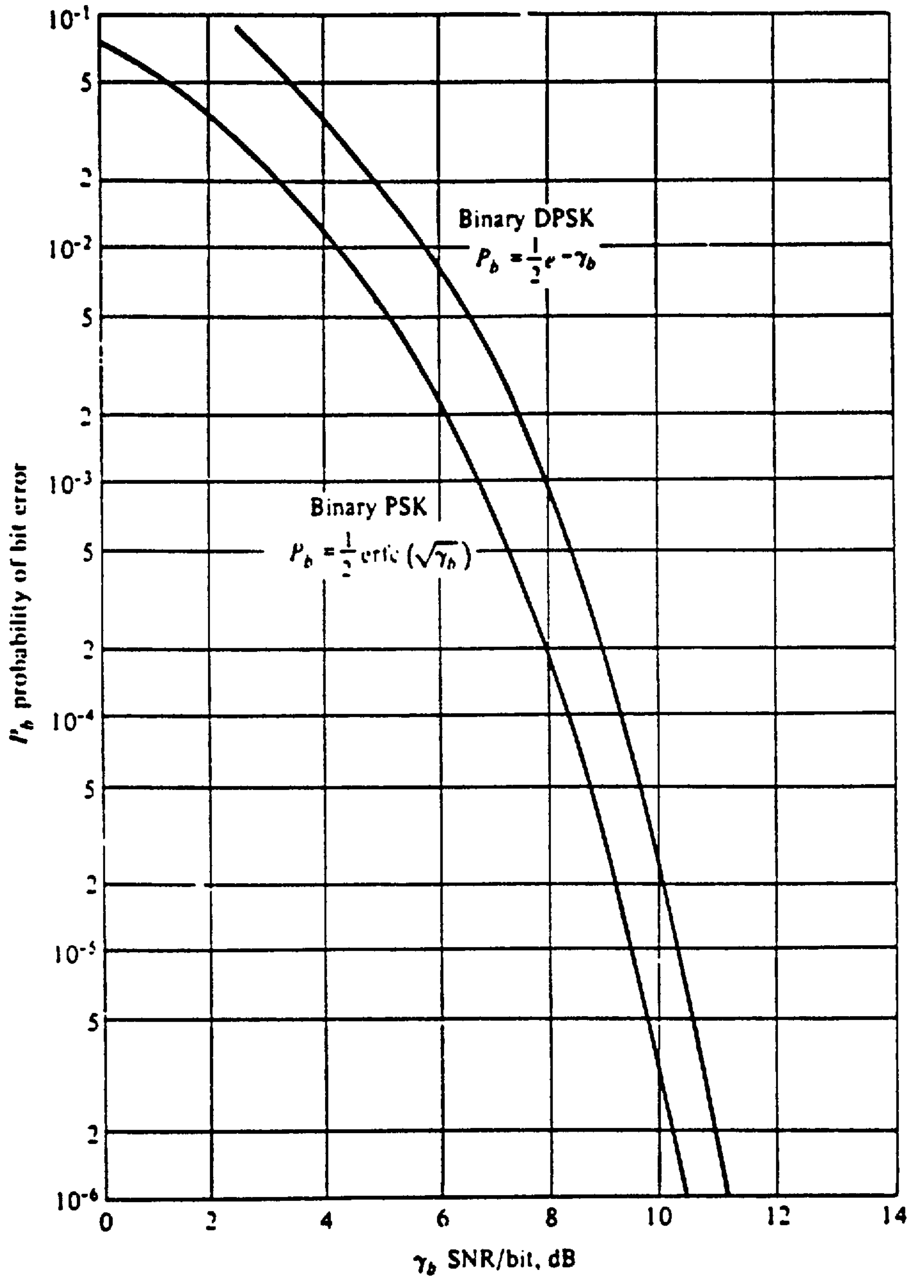


Figure 7.2. Performance of Binary Coherent and Noncoherent Modulations.

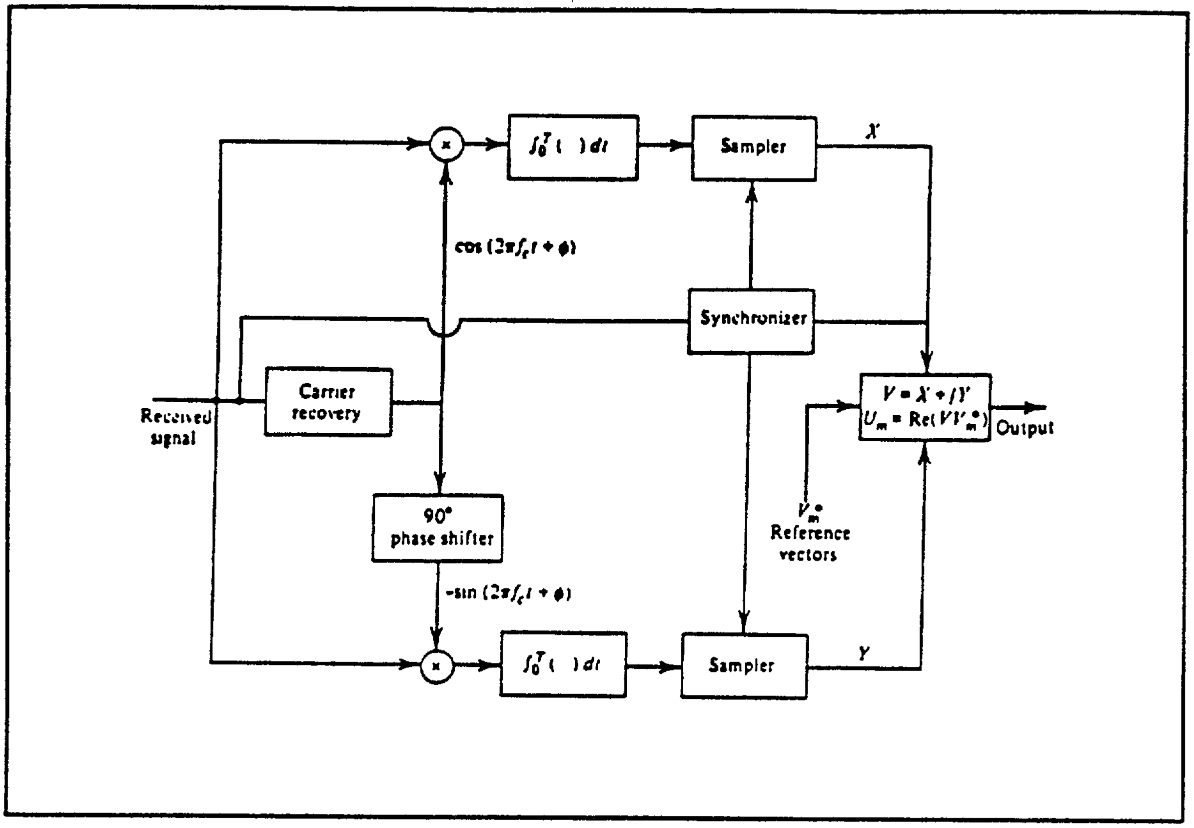


Figure 7.3. Block Diagram of a Coherent Receiver.

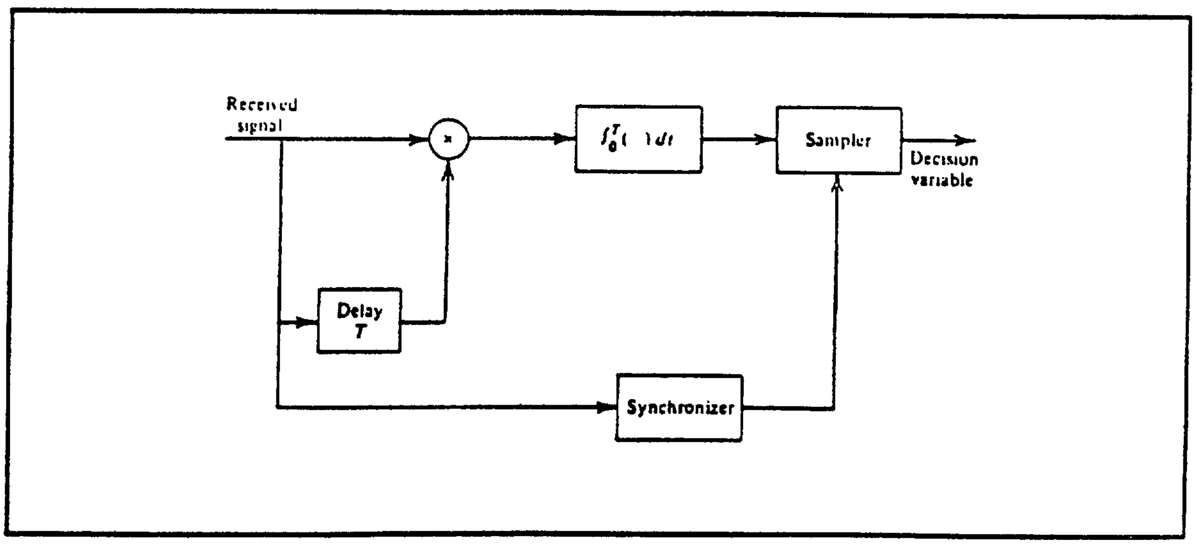


Figure 7.4. Block Diagram of a Noncoherent Receiver.

BPSK is the simplest of the coherent binary signalling schemes yet still rquires a Costas PLL instead of a standard PLL. Standard PLL are now sold as integrated circuits for less than 10 dollars. However, a Costas PLL costs more than the 100 dollar price goal for the entire IVSAWS vehicle unit. Furthermore, because phase must be tracked during the entire message, oscillators must drift less than one part per million. To achieve this stability, oscillators must be temperature compensated (TCXO). The price of a TCXO again exceeds the 100 dollar price goal for the entire IVSAWS vehicle unit. The 1.5 dB signal power savings of BPSK modulation reduces the transmitter power from 4 Watts to 2.8 Watts. Because 4 Watts is already below one of the major FCC transmit power limits (as in CB radios) and because the link budget is potentially dominated by 30 dB of foliage losses, the 1.5 dB power savings is not significant. Due to these receiver complexity and cost issues, BPSK is not appropriate for IVSAWS.

M-ary modulations provide signal power savings and have inherent error correction capabilities at the expense of receiver complexity. In M-ary modulation, data bits are processed in groups of n bits. The n bits select one of M signals for transmission, where $M = 2^n$ The receiver demodulates the signal by comparing the transmitted signal with a stored version of each of the M signals. The receiver picks the closest match and outputs the n bits corresponding to the selected signal. For the receiver correlation process to yield the correct signal choice in the presence of noise, each signal in the set of M signals must be as distinct as possible from all other signals in the signal set. The signals must have large auto-correlations and small cross-correlations. Such signals are called orthogonal signal sets. The signal designs to achieve these correlation properties are based on Hadamard matrices and Cyclic Code Shift Keying (CCSK). In an M-ary signal set, the 32 chip spreading rate is obtained by grouping 8 bits together and transmitting one of 256 signals base on the content of the 8 bits. For illustration ease, Figure 7.5 gives the example of 8-ary modulation in which 3 bits are used to select 1 of 8 signals.

For M-ary modulation, the demodulation process of picking the closest signal is essentially the concept of error correction. As the signal gets longer, occasional chip errors have minimal impact on selecting the correct signal. Figure 7.6 gives the BER performance curves for M-ary modulation. As M increase, less signal energy is required for the same performance but receiver costs increase. For M-ary demodulation, the oscillator stability must be maintained throughout the entire length of the M-ary signal. A 256-ary signal is the length of 8 spread data bits. Thus the receiver oscillators for M-q modulation must be at least 8 more stable than the receiver oscillators for binary modulations. Expensive temperature compensated oscillators, again on the order of one part per million, are required for the 256-ary modulation. Therefore, DPSK is also not appropriate for IVSAWS.

Example 1: Hadamard Sequences, M=8

S1:	-1	-1	-1	-1	-1	-1	-1	-1
S2:	-1	1	-1	1	-1	1	-1	1
S3:	-1	-1	1	1	-1	-1	1	-1
S4:	-1	1	1	-1	-1	1	1	-1
S5:	-1	-1	1	-1	1	1	1	1
S6:	-1	1	-1	1	1	-1	1	-1
S7:	-1	-1	1	1	1	1	-1	-1
S8:	-1	1	1	-1	1	-1	-1	1

Example 2: CCSK Sequences, M=8

S1:	-1	-1	-1	-1	-1	-1	-1	-1
S2:	-1	1	1	-1	-1	1	-1	1
S3:	-1	1	1	1	-1	-1	1	-1
S4:	-1	-1	1	1	1	-1	-1	1
S5:	-1	1	-1	1	1	1	-1	-1
S6:	-1	-1	1	-1	1	1	1	-1
S7:	-1	-1	-1	1	-1	1	1	1
S8:	-1	1	-1	-1	1	-1	1	1

Figure 7.5. Signal Formats for 8-ary Modulation.

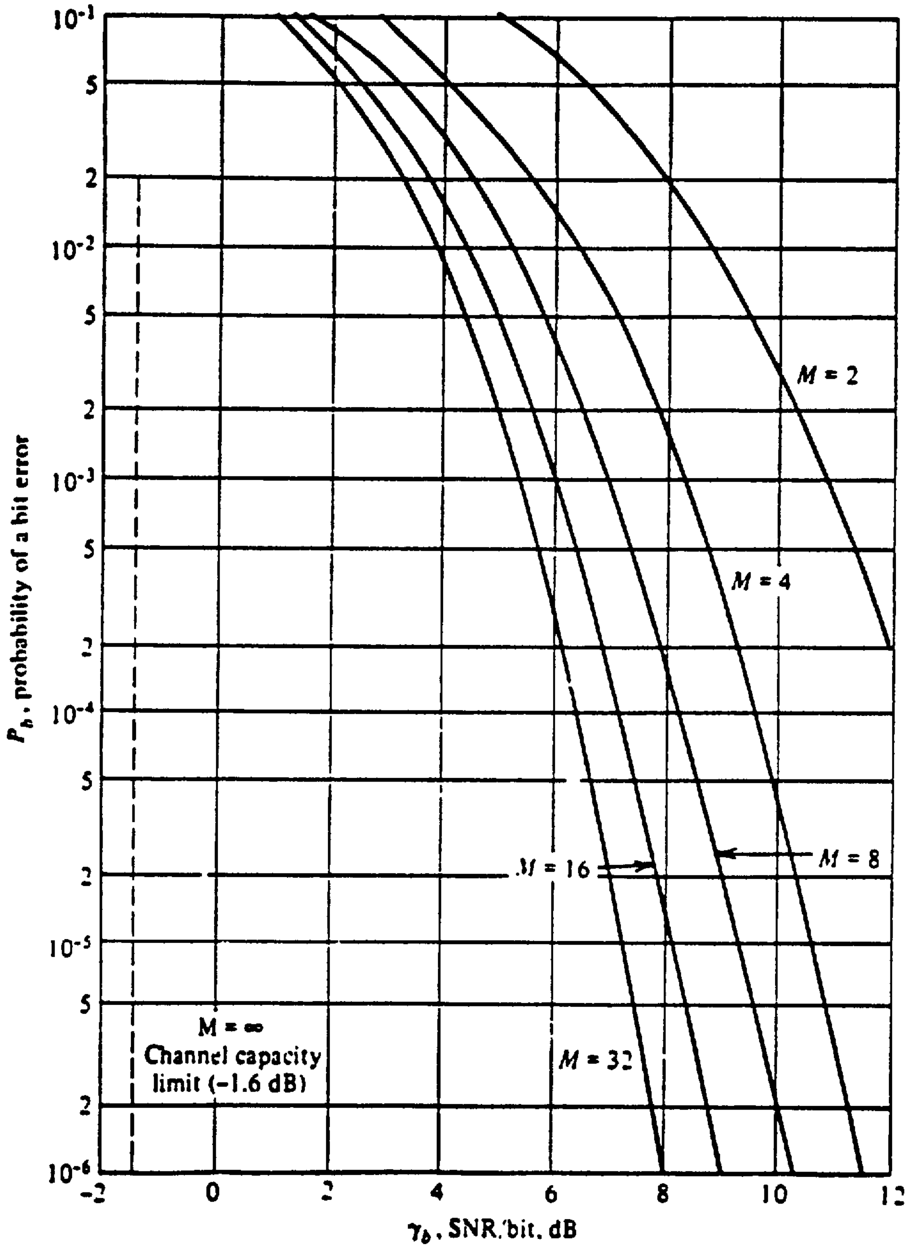


Figure 7.6. Performance of M-ary Modulations.

DPSK is the simplest of the coherent signalling schemes. Phase stability of the oscillators is only required during the demodulation of data bit time rather than over the entire message. The message starts with a reference data bit. Successive data bits are differentially encoded. A 0 phase change indicates that the current data bit is the same as the previous data bit. A π phase shift indicates that the current data bit is different than the previous data bit. A Costas PLL is not required because the carrier phase is never referenced in the demodulation process. The absence of expensive PLL and TCXO makes DPSK modulation the appropriate choice for IVSAWS.

7.6 Forward Error Correction Issues

For error free transmissions, two strategies are used: automatic repeat request (ARQ) and forward error correction (FEC). In ARQ, packets received without error are positively acknowledged (ACK) and packets received with errors are negatively acknowledged (NAK) so that the transmitter knows whether or not to repeat transmissions of message packets. In FEC, redundancy bits are appended to the actual data bits. The redundancy bits are calculated in an organized manner so that locations and magnitudes or errors can be calculated at the receiver. Example FECs in common usage are Hamming, Reed Solomon, Golay, and Convolutional. The FECs considered for IVSAWS are listed in Table 7.4.

Table 7.4. Candidate Forward Error Correction Codes

FEC TYPE	FEATURES	COST
Hamming (7,4)	Corrects 1 error in 7 bits 0.5 dB improvement 10^{-6} BER	$ 20.00
Golay (24,12)	Corrects 3 errors in 24 bits 1.4 dB improvement 10^{-6} BER	Implemented in Software
Reed Solomon (32,16)	Corrects 7 errors in 32 symbols 3.1 dB improvement 10^{-6} BER	$ 500.00
Viterbi Convolutional	Burst error correction 3.6 dB improvement 10^{-6} BER	$ 300.00
256-ary	Corrects 63 errors in 256 chips 4.6 dB improvement 10^{-6} BER	Demodulator Complexity

In a communication system which uses a FEC, the redundancy bits are information in addition to the user data bits which must be transmitted. In non-spread spectrum communications, the FEC redundancy bits may be an overhead that the system throughput rquirements may not tolerate. In a spread spectrum system, the FEC redundancy bits become part of the waveform spreading. Incorporating an FEC then depends on the noise environment, the transceiver cost goals, and whether or not the FEC processing delays can be tolerated. Figure 7.7 shows the resulting BER performance in Additive White Gaussian Noise (AWGN) when the FEC candidate algorithms arc combined with DPSK. For IVSAWS, engine ignition noise and co-channel interference must also be considered. The cost /performance tradeoffs arc discussed below with these performance issues in mind

Once the bit error rate is known, the message error rate (MER) can be computed. The MER is given by the following equation,

$$MER = 1 - \left[(1 - BER)^{length} \right]$$

where length is 1056 for the Alert message and 84 for the RTT messages. The MER performance for the Alert message is given in Figure 7.8. The MER performance for the RTT messages is given in Figure 7.9.

The 256-ary modulation requires the least signal energy of the waveforms considered to maintain a 10-6 BER. However, the 256-ary modulation requires a temperature compensated oscillator which exceeds the cost goal of the entire IVSAWS vehicle unit. The DPSK modulation with either Convolutional or Reed Solomon codes also provides rquires sizably less signal energy than DPSK modulation alone to maintain a 10-6 BER. However, both Convolutional and Reed Solomon codes rquirc complex decoders. Although these decoders are available in VLSI implementations, the cost for each of these two decoders again significantly exceeds the cost goal of the entire IVSAWS vehicle unit. The affordable FECs are the Hamming and Golay codes. To determine if either of these coders are necessary, the engine ignition noise and potential co-channel interference must be evaluated.

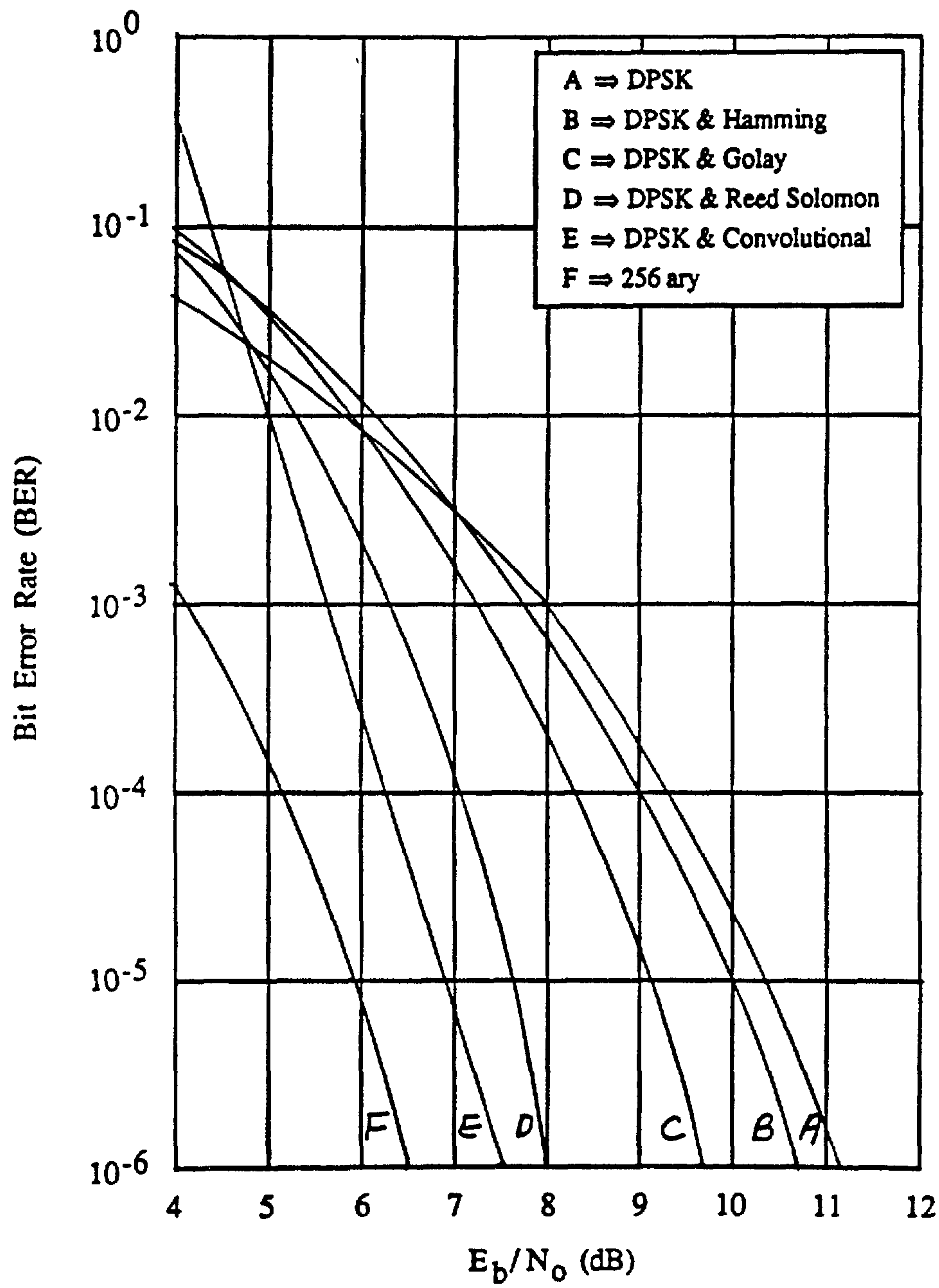


Figure 7.7. BER Performance of DPSK Modulation with FEC.

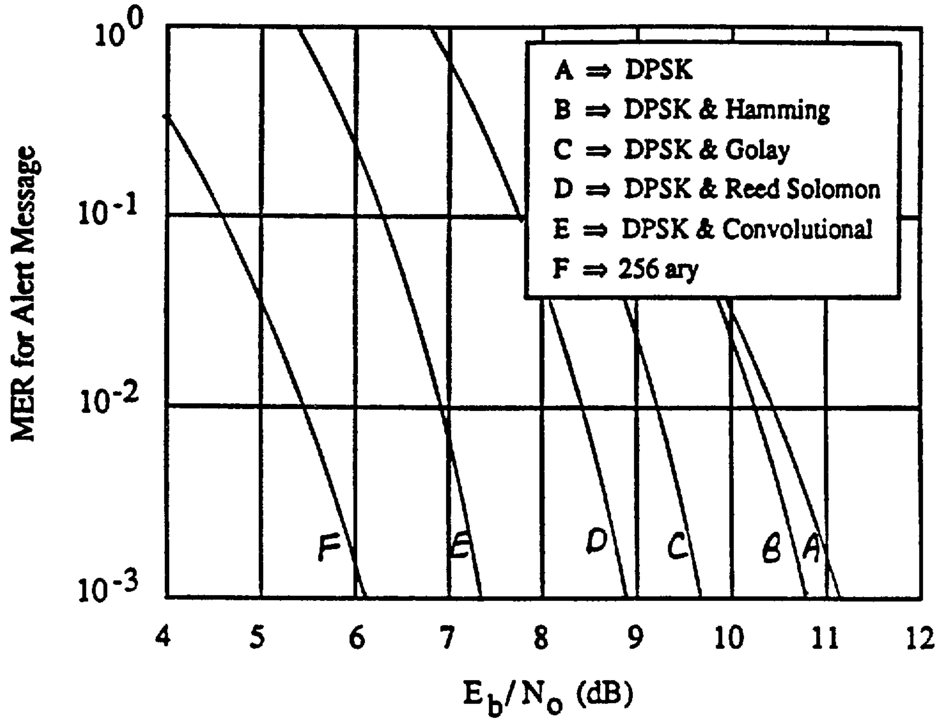


Figure 7.8. MER Performance for Alert Message.

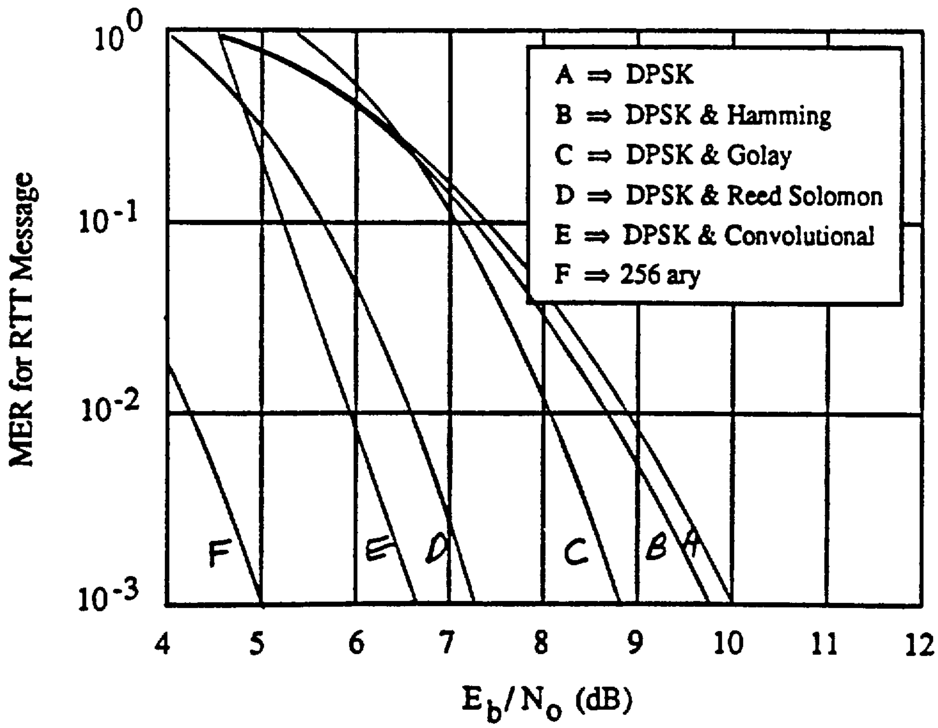


Figure 7.9. MER Performance for RTT Message.

Data was obtained from General Motors on the RF characteristics of engine ignition noise. Each spark plug firing produces a burst with 2 microseconds duration. This burst will potentially interfere with 10 out of 32 chips in the spread spectrum waveform. The time duration between spark plug ignitions even at high engine RPMS is much greater than the durations of both the Alert message and RTT message. Therefore, each IVSAWS transmission will be affected by at most one spark plug ignition. Furthermore, the RF energy generated by engine ignition is below the frequency band recommended for IVSAWS. Figure 7.10 shows the characteristics of RF energy from an engine ignition. Above 300 MHz, the RF energy is down at least 20 dB from the peak value. Thus engine RF noise will not impact the IVSAWS waveform anywhere in the 420 MHz to 450 MHz Frequency band.

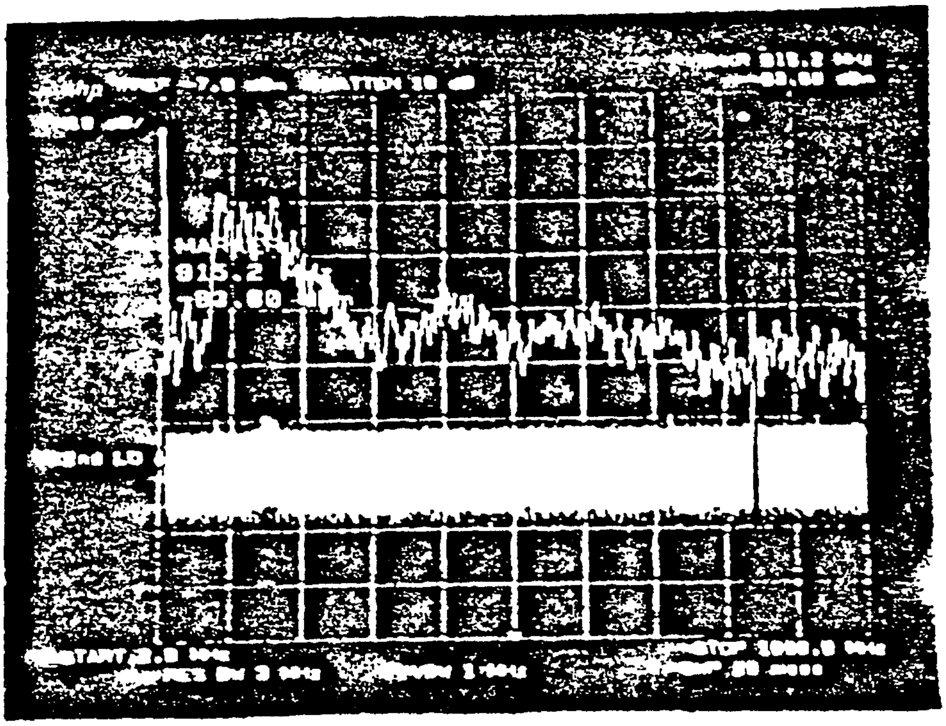


Figure 7.10. RF Characteristics of Engine Ignition Noise.

The other potential noise source in the 420 MHZ to 450 MHz frequency band is the Pave Paws radar. This radar produces a 16.1 millisecond pulse every 54 milliseconds. From Figure 5.2, the IVSAWS AIert message transmission is 6.875 milliseconds and the IVSAWS RTT message transmission is 0.547 milliseconds. When a Pave Paws transmission coincides with a IVSAWS transmission, the Pave Paws nansmission duration exceeds both IVSAWS message durations. Thus, the effect of the Pave Paws transmission will be an increase in the noise background for the entire message demodulation. Random errors occur in messages when the average noise level is low and the peak noise level is occasionally high for durations much shorter than the message length. Error correction codes provide reliable transmission by correcting these random errors. Rather than adding a FEC, the Pave Paws increase in the noise floor has a similar effect to foliage attenuation. The IVSAWS link budget already has at least 30 dB in the link margin designated for this type of situation.

Of the affordable FEC, the Golay code provides much better performance than the Hamming code. The IVSAWS units are microcontroller based and the Golay code is readily implemented in software. Referring to Figure 7.8, the Golay code provides 1.6 dB of performance improvement at 10-3 MER over DPSK alone for the entire alert message. The Golay code produced a 24 bit codeword for every 12 message bits. The RTT message would have 7 Golay codewords and the Alert message would have 88 codewords. Hughes has implemented the Golay codeword in software within several radios. For the 8 bit microcontroller, each Golay codeword would require 120 microseconds to decode. The microcontroller could not complete message decoding in time to respond within an RTT slot Hence, because of the combination of cost issues, processing speed issues, and sufficient link margin, a FEC has not been incorporated into the IVSAWS comminication link wavefonn.

7.7 PREAMBLE PERFORMANCE

The IVSAWS transmissions are bursty rather than continuous like an AM or FM radio. Thus every message reception begins with a “message search”. The receiver continuously generates analog to digital samples of the ambient signal. The correlator circuit compares the data samples with the known preamble pattern. When the match is sufficiently close, the correlator declares a message detection and provides initial timing. The initial timing is refined during subsquent symbols so that the data can be demodulated properly. The correlator works on the principle of energy detection. The length of the preamble must provide sufficient energy so that the preamble is readily distinguishable from noise.

In preamble design, the required preamble quality is determined. The quality of the preamble is measured by the probability of detection, Pd, and the probability of false alarm, Pfa. Higher Pd and lower Pfa imply that a greater total preamble energy to noise ratio is required. Each preamble pulse has a finite amount of energy. So to obtain the required total energy,

energy from separate preamble pulses are combined resulting in preamble processing gain. When pulses are combined, some of the energy is lost due to implementation losses, called nonlinear combining losses. Thus higher P_d and lower P_{fa} imply longer preambles. Excessive P_d and P_{fa} yield preamble lengths whose overhead cannot always be tolerated in a digital communication system.

Probability of detection, P_d, indicates the probability that the system will detect the presence of a message when a message is actually *present. Normally, P_d is* set to at least 0.99. In a system invoking safety, $P_d = 0.999$ is preferred, meaning that the system will detect 99.9 % of all messages present.

Probability of false alarm, P_{fa}, indicates the probability that the system will declare that a message is present when actually only noise is present. During a false alarm, the receiver continues to demodulate the false message, blocking itself from potentially receiving any true messages. For IVSAWS at most 1 false alarm in 4 hours of driving was selected as the design requirement. A digital receiver makes a decision about the presence of a message every chip time. Thus every chip time is a potential false alarm. The P_{fa} is calculated by combining the desired false alarm recurrence rate and the 5 MHz spread spectrum waveform chipping rate.

$$\text{opportunities} = \frac{5 \cdot 10^6 \text{ chips}}{\text{sec}} \cdot \frac{3600 \text{ sec}}{\text{hour}} \cdot 4 \text{ hours} = 7.2 \cdot 10^{10}$$

$$P_{fa} = \frac{1}{7.2 \cdot 10^{10}} = 1.4 \cdot 10^{-11}$$

Thus the calculated P_{fa} requirement is $P_{fa} = 1.4 \cdot 10^{-11}$.

The P_d and P_{fa} determine the required total preamble energy to noise ratio. This preamble energy to noise ratio is obtained from the graph shown in Figure 7.11 [1]. For $P_d = 0.999$ and $P_{fa} = 1.4 \cdot 10^{-11}$, the required preamble energy to noise ratio is 17.4 dB. A preamble is balanced to the strength of the data pulses that follow the preamble. Thus, the net rquired preamble processing gain in dB is the difference between the required preamble energy to noise ratio and the data demodulation signal to noise ratio. The data demodulation threshold for the baseline design is 11.1 dB. As shown in Table 7.5, the required net preamble processing gain is 6.3 dB.

Table 7.5. Required Preamble Processing Gain

Preamble Energy to Noise Ratio Pd = 0.999 and Pfa = $1.4 \cdot 10^{-11}$	17.4 dB
Data Demodulation SNR Threshold	11.1 dB
Minimum Required Preamble Processing Gain	6.3 dB

The gross processing gain of the energy that results from combining the energy of all the preamble pulses. This is the length of the preamble in dB. The baseline design has 16 pulses.

$$10\log(16) = 12\text{dB}$$

When pulses are combined, some of the energy is lost due to implementation losses, called nonlinear combining losses. These nonlinear combining losses are obtained from the graph shown in Figure 7.12 [2]. When 16 pulses at 11.1 dB are integrated, the nonlinear combining losses are 2.9 dB. As shown in Table 7.6, the net preamble processing gain is 9.1 dB.

Table 7.6. Communication Link Preamble Processing Gain

Preamble Gross Processing Gain 10 log (16)	12.0 dB
Nonlinear Combining Losses (16 pulses)	2.9 dB
Net IVSAWS Preamble Processing Gain	9.1 dB

The IVSAWS baseline design has 9.1 dB of net preamble processing gain. To achieve a Pd = 0.999 and Pfa = $1.4 \cdot 10^{-11}$, the minimum required preamble processing gain is 6.3 dB. The IVSAWS baseline design of 9.1 dB exceeds the minimum required 6.3 dB, so the IVSAWS communication link achieves a probability of detection equal to 0.999 and a probability of false alarm equal to $1.4 \cdot 10^{-11}$

7.8 REFERENCES

[1] L. V. Blake, A Guide to Basic Pulse Radar Maximum Range Calculations, Pan 1, Report 6930, Naval Research Laboratory, Washington, DC., December, 1969.

[2] J. D. Edell, Wideband, noncoherent, frequency hopped waveforms and their hybrids in low probability of intercept communications, Report 8025, Naval Research Laboratory, Washington, DC., November, 1976.

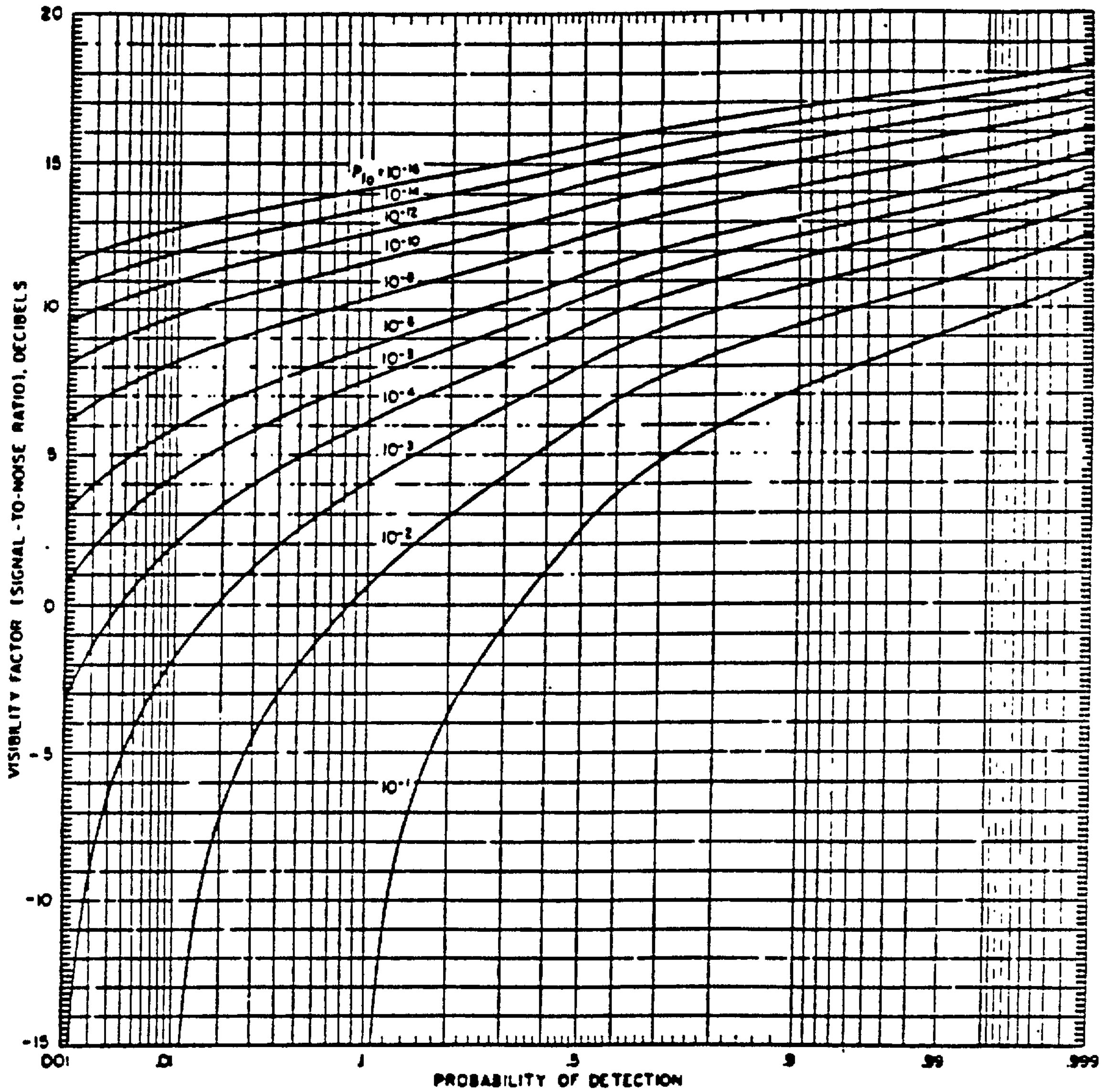


Figure 7.11. Required Preamble Energy to Noise Ratio as a Function of Probability of Detection and Probability of False Alarm.

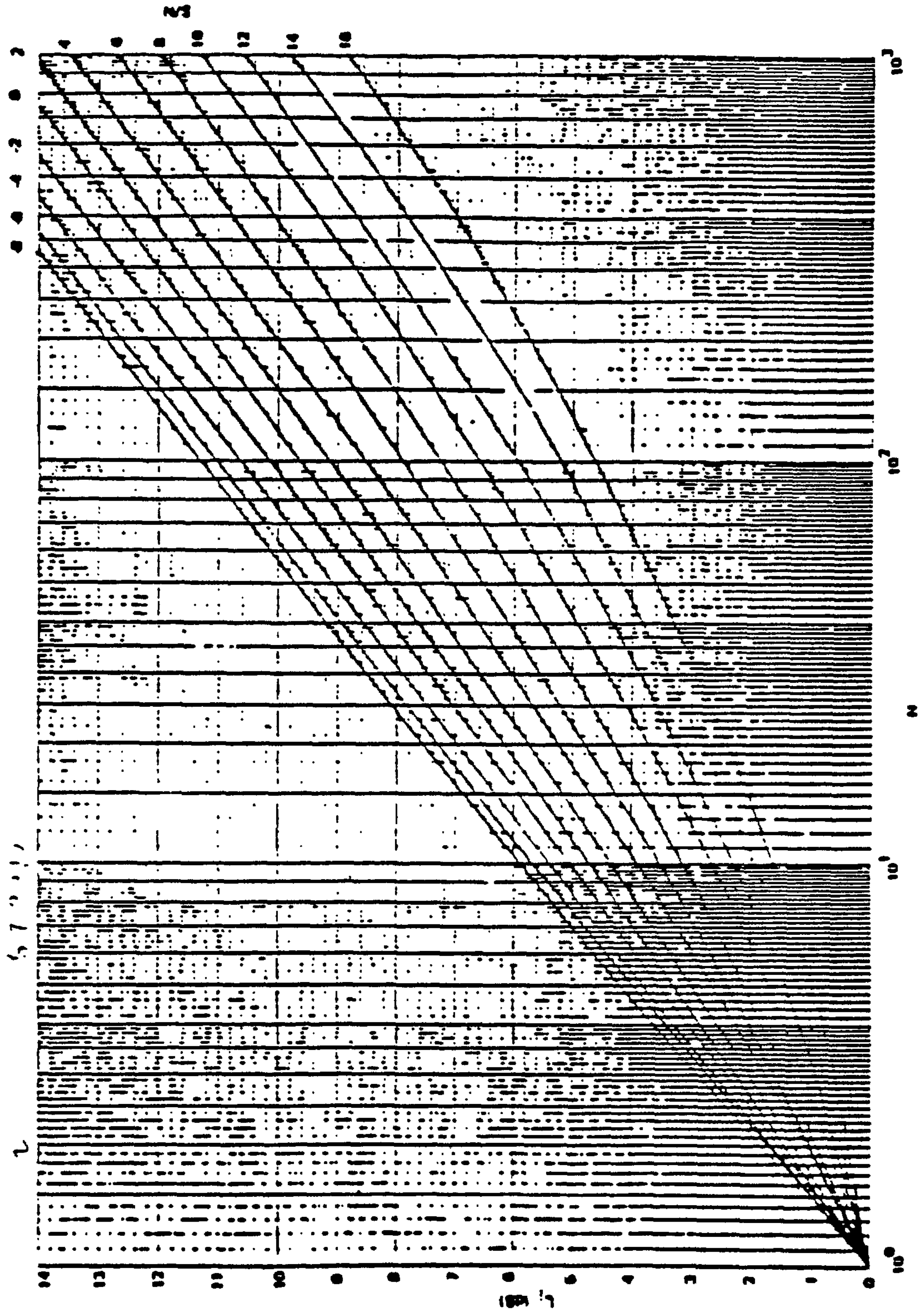


Figure 7.12. Nonlinear Combining Losses L as a Function of the Number of Pulses Integrated N and the Signal to Noise ratio S/N of the Pulses.

8.0 VEHICLE ANTENNA EVALUATION

8.1 SUMMARY OF FINDINGS

Two monopole whip antenna options were evaluated using computer simulation. The first antenna option is a standard automotive adjustable length antenna that has traditionally been used on vehicles for the AM-FM radio. This antenna would be shared by both IVSAWS and the entertainment system without any modifications. The second antenna option is a fixed length whip antenna specifically design for dual band operation with both the IVSAWS and the AM/FM bands.

Sharing an existing adjustable length antenna with the AM/FM radio has the potential for significant losses because the impedance match and antenna pattern vary with the length. Both parameters were found to be quite sensitive to changes in length. The best length for IVSAWS is 1.17 feet which is a half-wavelength. Simply adjusting the antenna to this length, however, will degrade FM reception severely. Conversely, entending the antenna to the optimum FM length significantly degrades IVSAWS performance. Therefore the recommended solution for new vehicles is to use an antenna specifically designed as a shared FM-IVSAWS antenna where the electrical length of the antenna is optimal for both bands.

A third option is a separate monopole antenna for the IVSAWS system. 'I-his is the easiest solution for retrofit installations, given that the standard FM antenna is unacceptable. The IVSAWS antenna could use a magnetic mount, or be permanantly installed, like cellular telephone antennas, at a driver's preferred location on the vehicle.

8.2 PROBLEM STATEMENT

The requirement that an antenna be capable of operating from a moving vehicle limits the types of antennas that can be considered Candidate types are further restricted when placement, polarization, silhouette, appearance, and cost factors are included. Having a single antenna for all types and models of vehicles is a challenge. It is expected that vehicle manufacturers will engineer a standard antenna design for a particular model or line of vehicles.

As outlined in the IVSAWS workplan, the most desirable situation would be to share an existing antenna already on the vehicle. This solution is the most cost effective for new vehicles and best satisfies the car designer's esthetic goals. Retrofit applications are also simplified if

IVSAWS can be quickly coupled into the existing antenna. However, initial doubts about existing vehicle antennas led to consideration of a dual-band AM-FM/IVSAWS antenna. A stand-alone IVSAWS antenna was not studied explicitly, but will have characteristics comparable to the dual-band antenna, because the dual-band antenna would be designed to appear electrically like an optimal-length stand-alone antenna.

For vehicle to vehicle communications, vertical polarization provides superior performance to horizontal polarization. In horizontally polarized signals, the ground wave tends to suffer from heavy destructive interference due to reflected energy. In vertically polarized signals, destructive interference occurs to a lesser extent and only at very small elevation angles. Therefore, even in terrain with the slightest hills, vertically polarized signals have far greater range than horizontally polarized signals in ground communications applicaitons . A vertically mounted monopole whip does provide vertically polarized signals.

The minimum length of an optimized monopole is 1/4 wavelength. Other longer lengths are possible provided the length is an integer multiple of 1/4 wavelength. For the shortest monopole, the free space elevation pattern is the “broadest” and no nulls exist besides the horizon and zenith. As the monopole lengthens, the elevation pattern changes and additional nulls begin to appear. At a half wavelength, the pattern is flatter with a narrower null at the horizon and a wider null at zenith. Because the pattern at the horizon is a primary concern, a half wavelength is recommended where feasible.

As shown in Figure 8.la, the first option is a single band monopole antenna. The easiest and most economical type of antenna is the monopole, a simple end-fed quarter wavelength conductor, mounted perpendicular to a ground plane. When placed atop a flat surface of a vehicle, a resonable ground plane is provided, forming the basis for most AM/FM vehicle antennas. The gain pattern of a monopole is similar to the gain pattern of a dipole with twice the length because the ground plane acts like a mirror. The resulting gain pattern is omnidirectional in azimuth (equal gain in any compass direction), has a null at zenith (straight up) like a dipole, and includes a null at the horizon.

As shown in Figure 8.1 b, the second option is a specifically designed dual band monopole antenna. A high frequency monopole can be incorporated into an existing AM/FM antenna. The whip for FM is typically a quarter wavelength long, roughly 2.5 feet. A monopole covering the 420 MHz region will need to be about 7 to 14 inches long, depending on design. It is possible to add a “trap” partially up the antenna at this height. The trap is basically a low pass filter with a cutoff point between the FM and IVSAWS frequencies. At high frequencies (420 MHz) the monopole radiates only from the bottom of the whip. At FM frequencies (100 MHz), the trap passes the signal, energizing the entire 2.5 foot monopole. The gain pattern of this antenna for each frequency band will be identical to the gain pattern for the single band design.

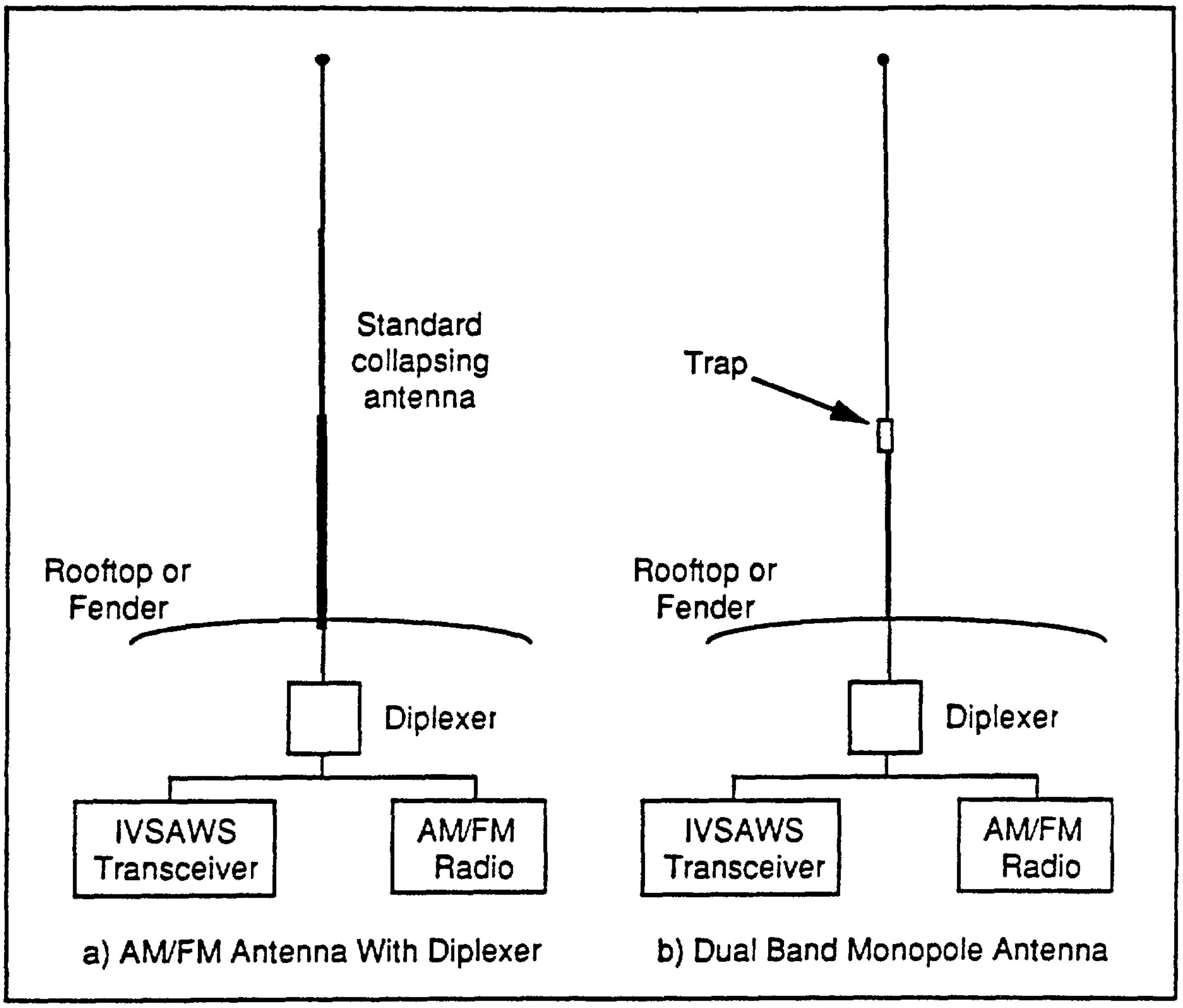


Figure 8.1 Two Vehicle Antenna Approaches Studied.

8.3 Study Methodology

A computer model was used to estimate the gain of an AM/FM IVSAWS shared antenna. This model uses the method of moments, which breaks the antenna into small elements for computational purposes. Inputs to the computer model are the antenna geometry, range to the receiver, terrain characteristics, antenna height, transmit power, transmit frequency, and the ground plane characteristics. Output from the model is the electrical field strength of the radiated signal at the specified range. This can be converted to a received power level, or simply the relative gain can be computed in dB as a function of azimuth or elevation angle. The latter was chosen for this study.

The model inputs were:

Frquency	420 MHz
Length	1.17, 2.0,2.5, 3.0 feet
Type	Monopole over good ground plane
Ground Dielectric Constant	15
Ground Conductivity	9E-3 mhos/meter
Range	1 Km
Terrain	Relatively Flat, No Trees

(The range was not critical since only a relative gain pattern was output. However, it is important to be in the far field, a condition easily met at 1 Ion.)

Key study questions are:

Regarding use of an existing AM/FM antenna.	How critical is the length of the AM/FM monopole antenna when shared for IVSAWS ?
Regarding use of a dual band antenna:	Are the patterns similar to a single monopole, and is it usable for the IVSAWS system ?
For either antenna system:	What is the expected antenna gain in the direction of the roadside unit ?
	What is the degradation from the horizon nulls which are inherent in a monopole antenna ?

The antenna length was varied around a mean of 2.5 feet, the optimum for the FM band. This is about 2 wavelengths at the 420 MHz IVSAWS frequency. The analysis was done to determine how sensitive IVSAWS would be to variations in antenna length. An additional case was computed for a length of 1.17 feet, which represents an optimum length half wave monopole for IVSAWS. This case represents either a stand-alone IVSAWS antenna or the IVSAWS segment of the dual-band antenna.

Figures 8.2, 8.3 and 8.4 show the elevation patterns for the IVSAWS signal when a standard AM/FM antenna is used at three different lengths. On these plots, 90' is the horizon and 0" is the zenith. Only half of the pattern is plotted, since it is symmetric. As predicted, there are nulls at the horizon and directly overhead. The peak gain in each case is over 6 dB, but this at an elevation angle of 45o to 60°, which is not useful for IVSAWS. The gain at 80" (10o above horizon) is less than -5 dBi in each case, although the 3 foot antenna did predict a positive gain value of 2.5 dBi at 5^0 above horizon.

In addition to the pattern plots, the antenna impedance was computed. The antenna impedance is given in Table 8.1. The impedance of the antenna changes as the length changes. There is an especially severe change between the nominal 2.5 foot case and the 2 foot case. If the receiver were matched to the 2.5 foot antenna (by adding a tuning coil to cancel out the capacitance of the antenna at 2.5 feet), shortening the antenna to 2 feet would cause a mismatch loss of 2.7 dB. The 3 foot antenna would cause a mismatch loss of 3.7 dB. This may not be the optimum matching strategy, but this data argues for a fixed length antenna. Another alternative is an automatic tuning network, which would increase the cost and complexity of the radio.

Figure 8.5 shows the elevation pattern for the the dual-band monopole antenna used at the IVSAWS frequency. The electrical length is 1.17 feet, which is a half wavelength at 420 MHz. The resulting pattern is comparable to that of a full wave dipole, which has a sharper peak gain and better gain close to horizon than a half-wave dipole. The gain of this antenna is quite good close to horizon - at 2o off horizon it reached 0 dBi. The impedance was also very close to a standard 50 ohms, as listed in the table, which simplifies matching to the power amplifier and low noise amplifier impedances, thereby minimizing circuitry.

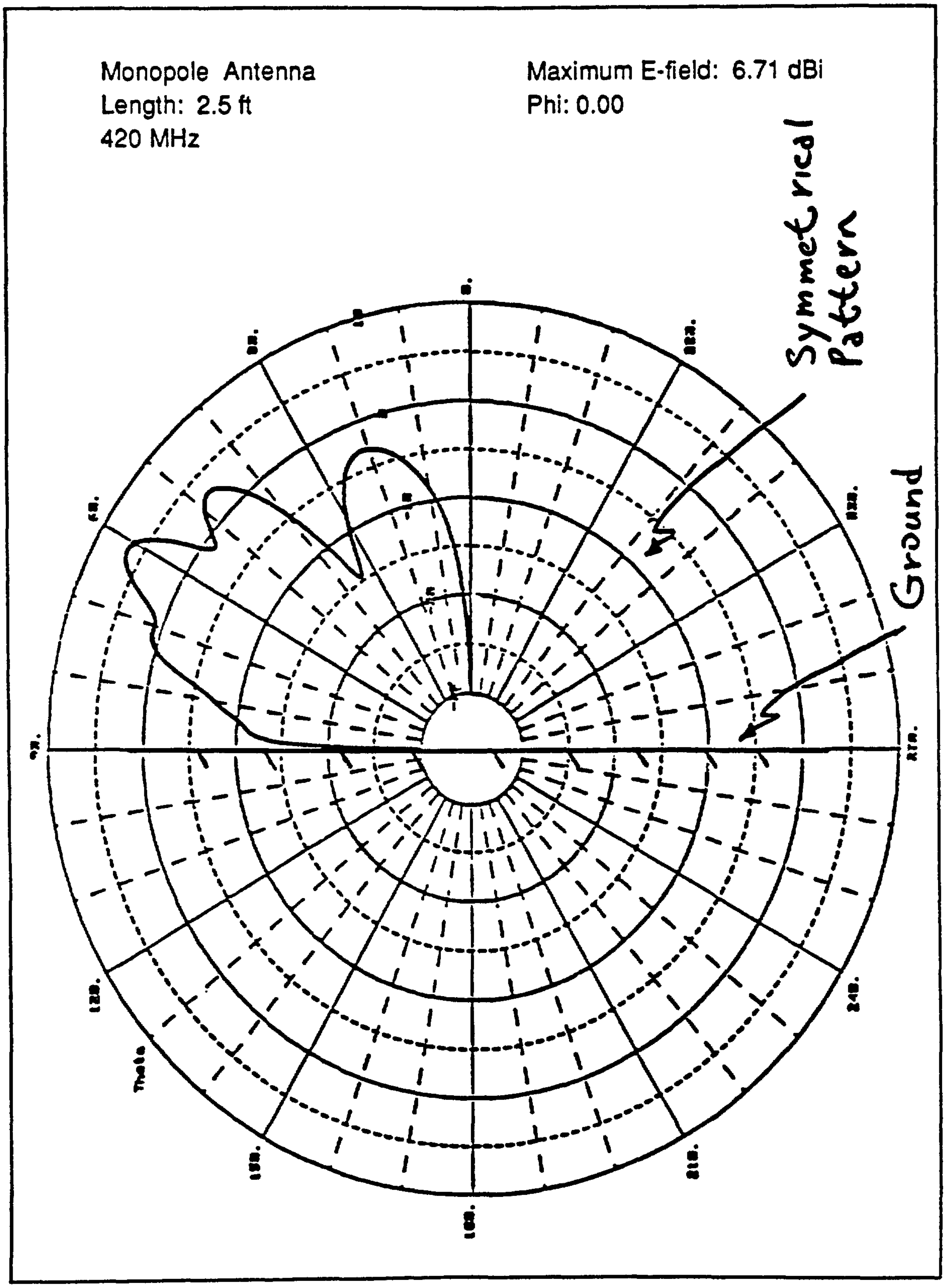


Figure 8.2. Gain Pattern for 2.5 foot Antenna.

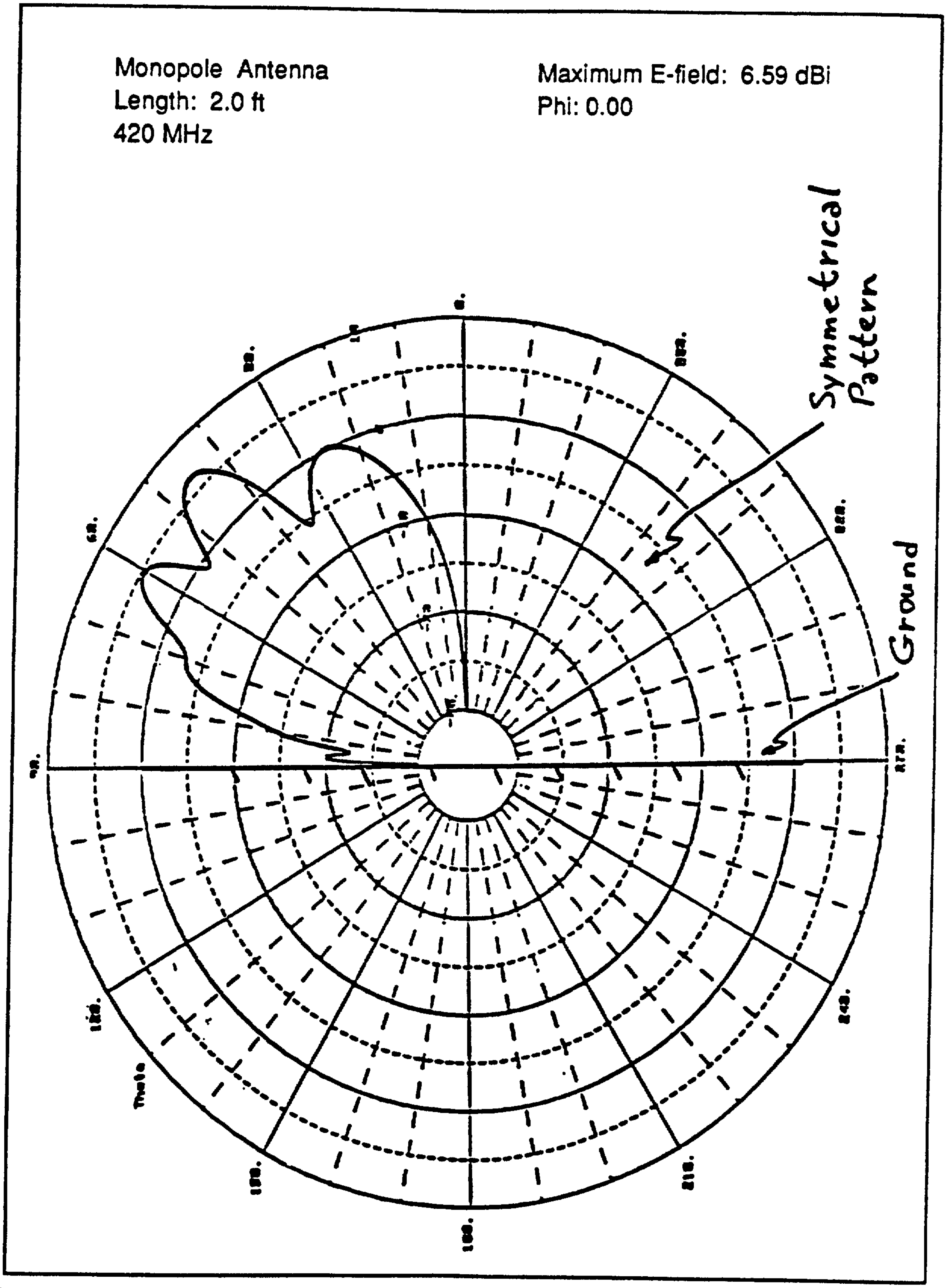


Figure 8.3. Gain Pattern for 2.0 foot Antenna.

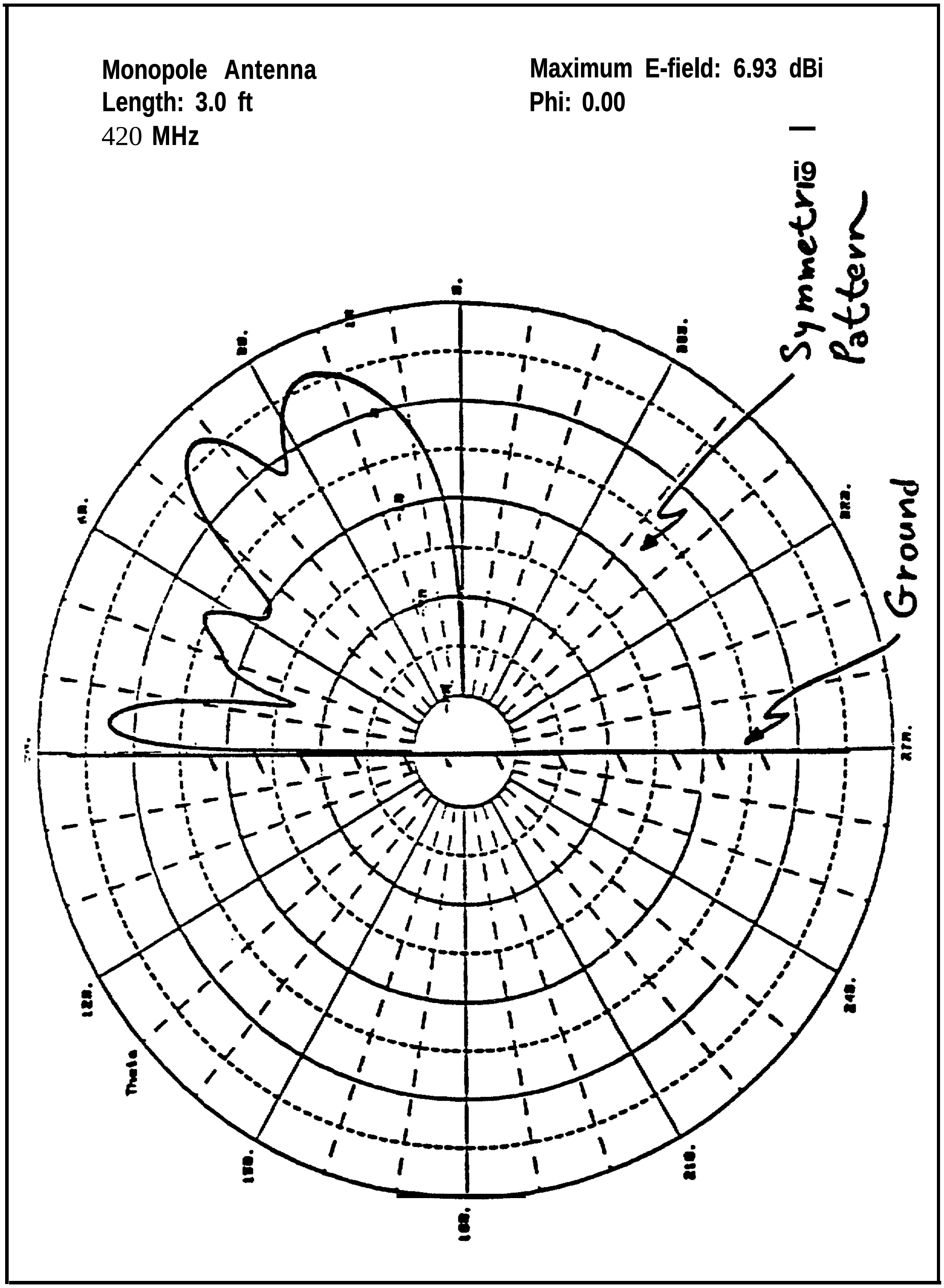


Figure 8.4. Gain Pattern for **3.0 foot Antenna.**

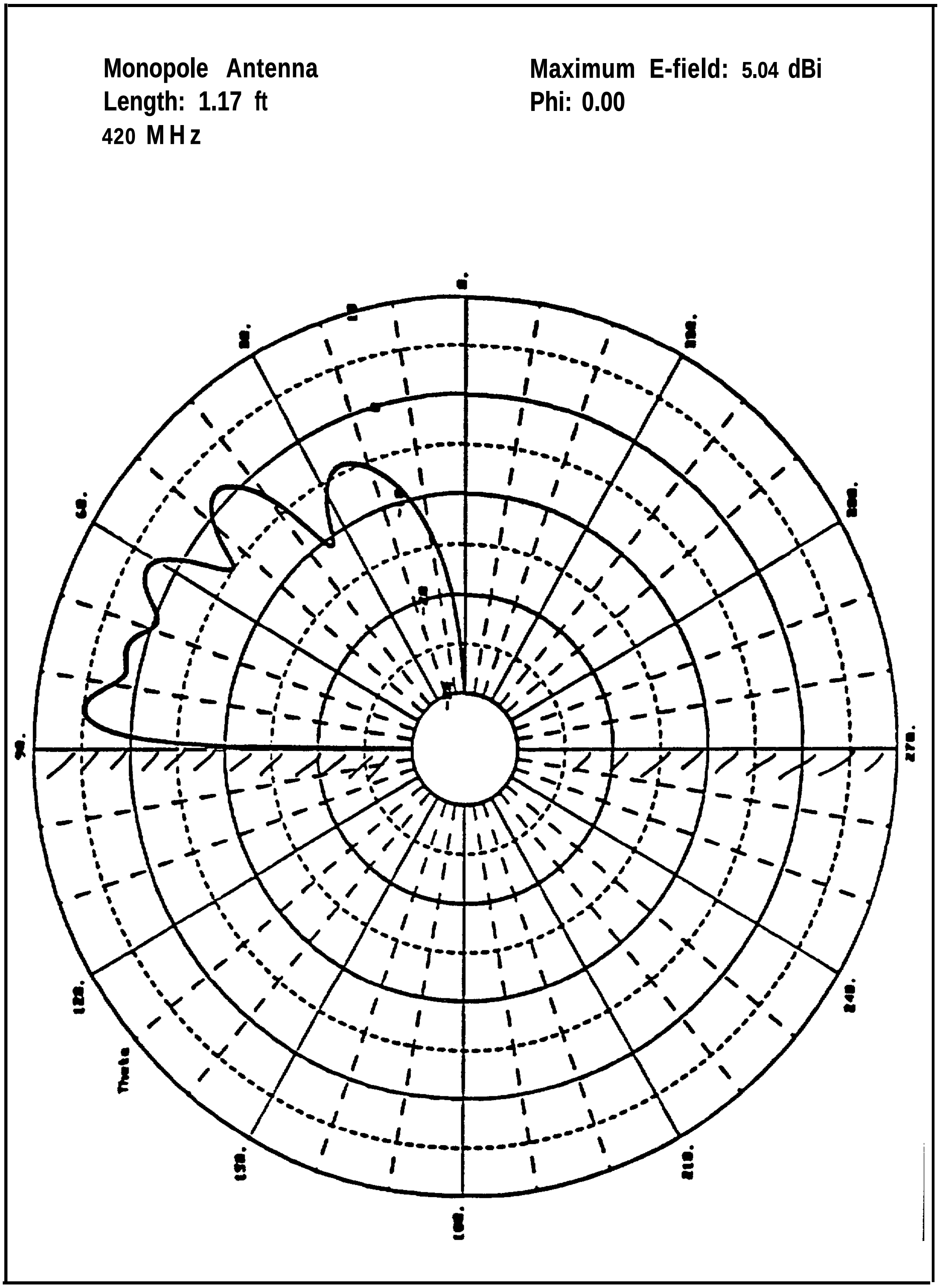


Figure 8.5. Gain Pattern for 1.17 foot Antenna.

Table 8.1. Antenna Gain and Impedance Characteristics

Monopole Length (feet)	Monopole Length (wave-lengths)	Complex Impedance (ohms)	Gain at 0.5° Off Horizon (dBi)	Gain at 5° Off Horizon (dBi)	Gain at 10° Off Horizon (dBi)
2.0	0.85	247 + j74	-31.6	-22.0	-13.8
2.5	1.07	95 - j170	-25.0	-10.9	-7.1
3.0	1.28	93 + j48	-11.2	2.6	-5.5
1.17	0.5	54 + j23	-10.4	5.0	2.3

The horizon null of a monopole is an important consideration, since if the vehicle and warning unit are both at the same elevation (i.e., the warning unit is at horizon), the antenna gain for the direct wave will be quite poor. Most two-way vehicular communications systems deal with this by placing transmitters or repeaters on mountains, towers, poles, or buildings. Alternately, extra link margin can be included to cover antenna losses.

This should not be necessary for IVSAWS, because sufficient link margin is being allocated to cover propagation anomalies. In the case of a clear line of sight on flat ground, there is about 40 dB of excess link margin in the design, which will more than compensate for the antenna characteristics. In a wooded situation, where the extra link margin will be required, the signal will have diffracted above the trees, propogated to the vehicle, then diffracted down toward the car. In this situation the effective elevation angle will be about 10” up from horizon and the antenna gain will not be nulled.

Vehicle mounting will also impact the antenna pattern and the horizon null. In producing the patterns, the ground plane was modeled as flat, fully reflective, and perpendicular to the monopole. In a typical front fender mount, however, the hood of the vehicle will tilt slightly forward which, when combined with the raised roof behind the antenna, will cause the pattern to be tilted toward the front horizon. This will reduce the size of the front horizon null. A rear fender mount will result in a pattern tilted toward the rear horizon, especially if the antenna is set at a slight angle (a common practice for the aerodynamic look). Modeling these effects was beyond the scope of this study, although it may warrant further investigation. A front fender mount position should be encouraged since reception biased toward the front of the vehicle is preferrable to a rear bias.

8.4 RECOMMENDATIONS

Based on these results the following recommendations are made regarding the vehicle antenna:

1) A fixed length antenna should be used to simplify tuning.
2) A monopole whip, either dedicated to IVSAWS or shared in a dual band arrangement as described earlier is recommended to maximize gain at horizon. A 1/2 wavelength monopole is recommended.
3) Further analysis and experiments should be performed to determine:
   a) The degree to which the gain pattern at horizon is a problem in real-life scenarios.
   b) What can be done to improve the pattern at horizon (e.g., tilting the antenna or placing it on a tilted surface of the car).

Field tests should answer some of the questions in the third recommendation. However, laboratory measurements on cars need to be applied at some point in order to optimize the antenna design and mounting. This would normally be up to the vehicle manufacturer, but some measurements would add insight into the general trends, which would help manufacturers make IVSAWS more effective.

9.0 RADIO FUNCTIONAL DESCRIPTION

9.1 RADIO OVERVIEW

The IVSAWS radio is designed for both the reception and transmission of digital messages between a warning unit and a vehicle unit. The radio is comprised of three major subassemblies — frequency conversion module, digital correlator/processor, and microcontroller. These three subassemblies, together with support functions, are shown for the warning unit in Figure 9.1 and for the vehicle unit in Figure 9.2. The frequency conversion module translates the radio signal between its assigned location in the frequency spectrum (where it propagates over the link) and baseband (where the information is placed on or extracted from the waveform). The digital correlator / processor performs different processing during transmission and reception. During reception, the digital correlator /processor extracts the digital information from the radio waveform and presents it to the microcontroller. During transmission, the digital correlator / processor encodes the information from the microcontroller onto the radio waveform. The micorcontroller controls the IVSAWS radio by storing messages and organizing the protocols used for message transfers. In the vehicle application, this module will also operate a driver display and execute software algorithms for the optimum display of hazard information.

Some additional functions are included to support these subassemblies. An antenna, roofing filter, switching, and a power amplifier are needed by the frequency conversion module. The correlator/processor requires a memory (RAM) circuit for message preamble detection. A crystal oscillator is needed by the microcontroller to establish basic timing. In a vehicle installation, the microcontroller will also utilize an electronic compass and a driver display. These would be deleted in a fixed warning installation. Either installation would include a microcontroller interface that can be used as a programming and test port. The software program for the two applications will be different, since the vehicle radio will be used as a receiver most of the time, while the warning unit will be transmitting. Finally, a power supply will provide the required voltages to operate the radio. This will be a 12 VDC unit for vehicle applications, while it may be a 110 VAC for fixed installations.

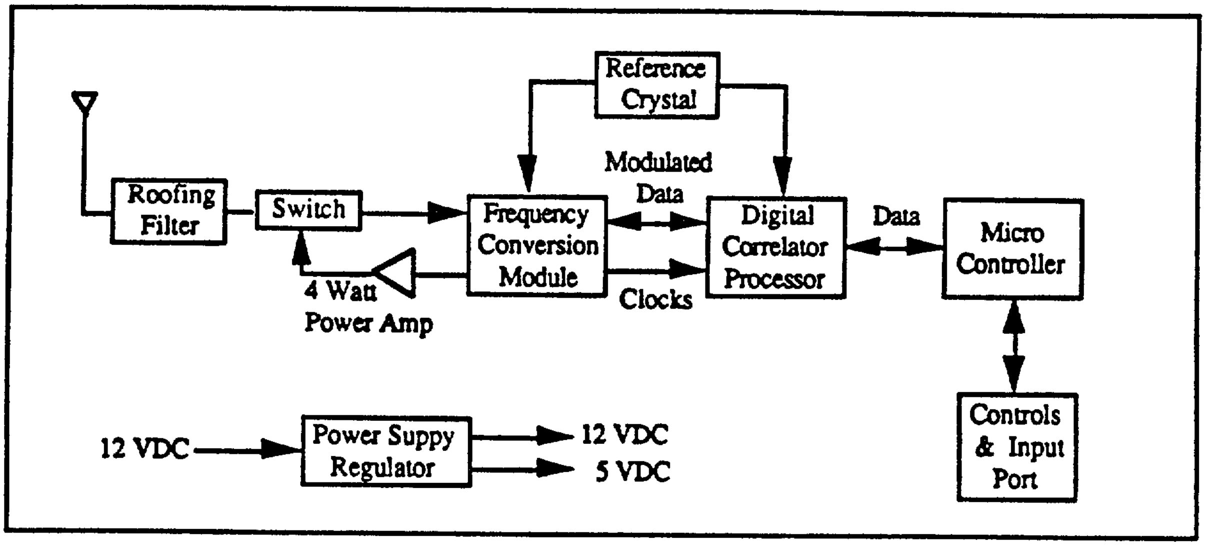


Figure 9.1 Block Diagram for IVSAWS Warning Unit.

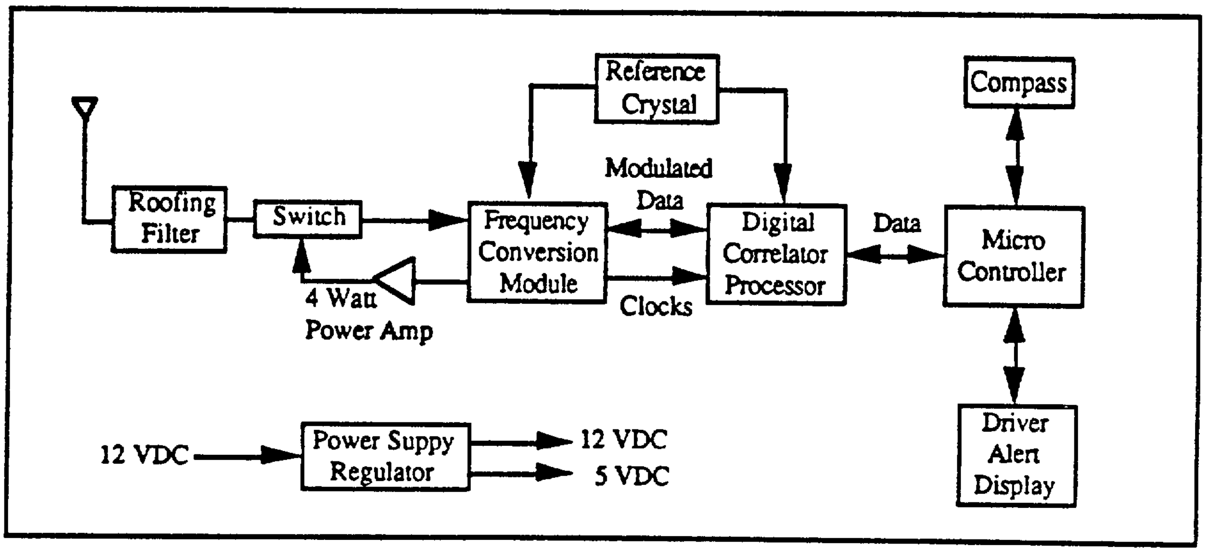


Figure 9.2 Block Diagram for IVSAWS Vehicle Unit.

9.2 RADIO FREQUENCY CIRCUIT DESCRIPTION

The radio frequency circuitry of the IVSAWS transceiver includes both receiver and transmitter circuitry, multiplexed to a common antenna. The receiver design uses a conventional heterodyne approach, downconverting the signal to an intermediate frequency, then converting it a second time to baseband for demodulation. The transmitter design uses a double upconversion technique. The local oscillators are shared with the receive circuitry. Figure 9.3 presents a block diagram of the transceiver, emphasizing the transmit and receive circuits.

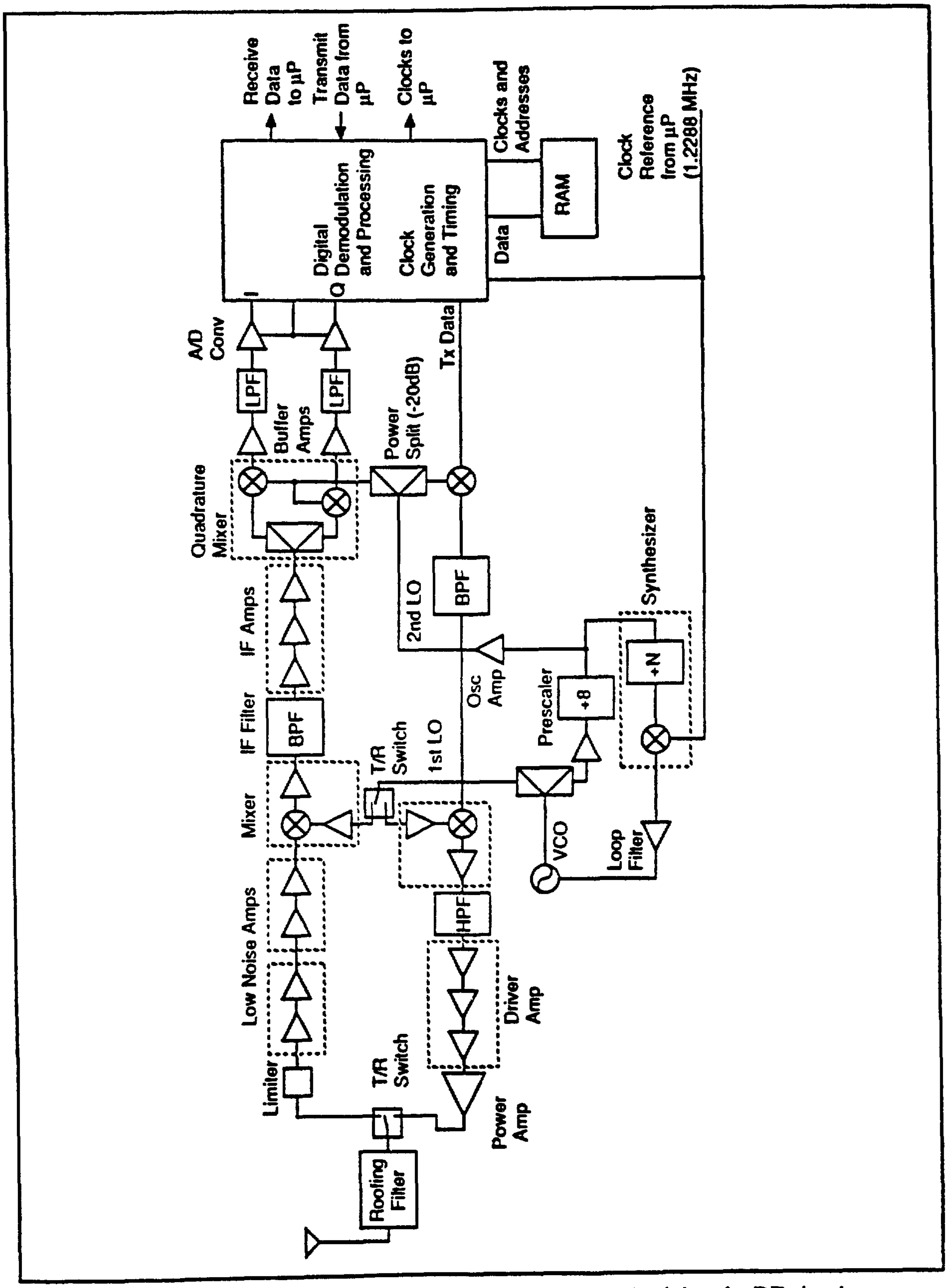


Figure 9.3 Detailed Block Diagram of the IVSAWS radio, emphasizing the RF circuitry.

The antenna feed is input through a roofing filter, an LC filter designed to pass the signal of interest and reject signals in neighboring frequency bands. During transmit this filter aids in rejecting spurs and signal harmonics. A transmit/receive switch connects either the transmit or the receive circuitry to the antenna.

The receiver uses a chain of low noise amplifiers to boost the signal by 40 dB. Noise figure for the resultant amplifier will be 2 dB, with another 1 dB each for the filter and switch, bringing the total noise figure to 4 dB An active balanced mixer is used to downconvert the signal to the intermediate frequency, where a bandpass filter selects the difference mixing product. This filter will be matched to the signal, setting the noise bandwidth of the system A surface acoustic wave (SAW) filter is prefened since it has a very linear phase response that minimizes signal distortion. It will have approximately 15 dB of insertion loss, however, which must be recovered with extra amplifier gain. The IF amplifier chain provides a minimum of 60 dB of gain with a clipping level of -10 dBm, effectively clamping at this level any antenna input signal down to the detectable signal level of -100 dBm. The limiting amplifier design eliminates the need for automatic gain control circuitry. Because the signal was transmitted as a constant amplitude signal and the information is contained in the phase angle, nothing is lost by using a limiting amplifier design.

The IF signal is split in a quadrature power splitter, which divides the power equally but phase shifts one of the two outputs by 90o The outputs are fed to TWO diode ring balanced mixers. The second local oscillator is fed to each mixer. This converts the signal into two baseband channels, an in-phase channel (I) and a quadrature channel (Q). In each channel, 20 dB of additional gain is required before the signal is fed to a simple low pass filter selects the difference mixing product. Two analog-to-digital converters, each operating at 19.6608 MHz (4 times the chip rate), sample the I and Q channels and output 2-bit amplitude estimates. These are fed to the digital demodulation circuitry, which derives the received data from the signal.

During transmit, the digital modulation circuitry substitutes the spread spectrum code for each data bit received from the microprocessor, and outputs the resulting 4.9152 MHz bit rate sequence to a mixer. A small amount of power from the second local oscillator is used to upconvert the bit sequence to the IF frequency. The signal is filtered, then fed to an active balanced mixer where the first local oscillator upconverts the bit sequence to the transmit frequency. The second local oscillator is routed through a transmit/receive switch, like the antenna signal, so that the same oscillator can be shared by the transmit and receive functions, minimizing circuitry. The control lines for these switches are operated by the microprocessor, The output of the second upconvenion mixer is filtered to select the sum mixing product, then supplied to an amplifier chain which boosts the power to a 4 Watt level (or slightly higher to account for switch and filter loss). This amplifier chain consists of a multi-stage driver amplifier and a power amplifier. The signal is then routed through the antenna T/R switch, through the roofing filter, and out the antenna.

The local oscillators arc generated using a synthesizer. Multiple oscillator signals can be generated using a single crystal reference, minimizing drift problems common to multiple frequency source designs. A voltage controlled oscillator is designed to operate at the frequency of the first local oscillator. This source is frequency divided by a factor of 8 and used as the second local oscillator. This output is further divided by a factor of N, compared against a 1.2288 MHz reference, and used to create an error signal to keep the VCO locked to a frequency which is 8N times the reference. With N set to 38, the various frequencies are set as follows:

First Local Oscillator Frequency	373.5552 MHz
Second Oscillator Frequency	46.6944 MHz
Transmit / Receive Frequency	420.2496 MHz

The exact transmit/receive frequency can be adjusted by selecting a suitable value for N. To aid in frequency adjustment, the N divider would be designed as a dual-modulus divider, capable of switching between two different divide ratios. For example, if the two divisors were 38 and 39, and the circuit was cycled with 38 used 3 of 4 times and 39 used the fourth time, the effective divisor would be 38.25 and the transmit frequency would shift up to 423.0144 MHz.

The reference frequency of 1.2288 MHz was chosen since that is a standard frequency widely used and supported in microprocessor systems. Many small microprocessors of the type suitable for this application are designed to operate at this rate. A wide selection of inexpensive parts are available. Since it was desirable to reference all system frequency sources to a single crystal to minimize frequency drift errors, the microprocessor crystal was used as the reference.

9.3 DIGITAL CORRELATOR /PROCESSOR CIRCUIT DESCRIPTION

The digital correlator/processor (DCP) performs key radio receive and transmit functions. These functions include detecting the presence of an incoming message, obtaining message and spread spectrum code timing, and extracting the information from the incoming data stream. The DCP interfaces with the RF frequency conversion module and with the microcontroller. Nearly all of the DCP is dedicated to receiving (as opposed to transmitting). This is typical of a digital spread spectrum radio.

The DCP's receive mode interface with the RF frequency conversion circuitry is at baseband - the carrier frequency has been removed and only the modulated information remains. The baseband data has already been sampled by analog-to-digital converters. The sampling process was performed in quadrature, meaning that the incoming signal has been split into two orthogonal channels, labeled I (for In-Phase) and Q (for Quadrature). The incoming signal therefore consists of two streams of numbers, as shown in Figure 9.4. The sample rate is set to 19.6608 MHz, four times the 4.9 152 MHz spread spectrum chip rate, to allow timing to be adjusted easily and to meet sampling theory (Nyquist) requirements with reasonable filtering. Each sample is a two bit number. Using two bits per sample minimizes processing losses without unduly expanding the circuitry requirements.

The DCP also accepts a 1.2288 MHz reference clock from the microconuoller circuitry. This reference is the basis for the digital clocks generated in the DCP. A common reference throughout the IVSAWS radio minimizes cost because only one stable crystal is needed. The DCP outputs recovered data and clock to the microcontroller at the baseline 153.6 KHz rate.

The DCP's message detection and initial timing functions are performed by the preamble correlator. The preamble correlator operates only during initial message search. Data samples are fed into the correlator at 9.8304 MHz, providing two samples per chip per dimension. The correlator circuitry is looting for the preamble bits at the start of the message, declares their presence, and provides initial timing. The correlator operates on the principal of energy detection. The transmitter sends a known and repeated pattern of 16 bits, which is spread by 32 chips, When double sampled in the receiver, each bit is represented by 64 samples of the incoming signal. The samples are compared against the known pattern in the correlator. The degree of match for each position is stored in a 64 position memory, and accumulated over the 16 bits. When the pattern is correctly identified, timing is known to within +/-1/4 of a chip period

Once preamble is detected, the preamble correlator is deactivated and the remainder of the DCP is activated. The PN stripping and code tracking circuit removes the 32 bit spreading code from the incoming chip stream. This is done by multiplying it by the fixed (and known) spreading code and accumulating for a bit time. This is possible since the code timing is already computed by the preamble correlator.

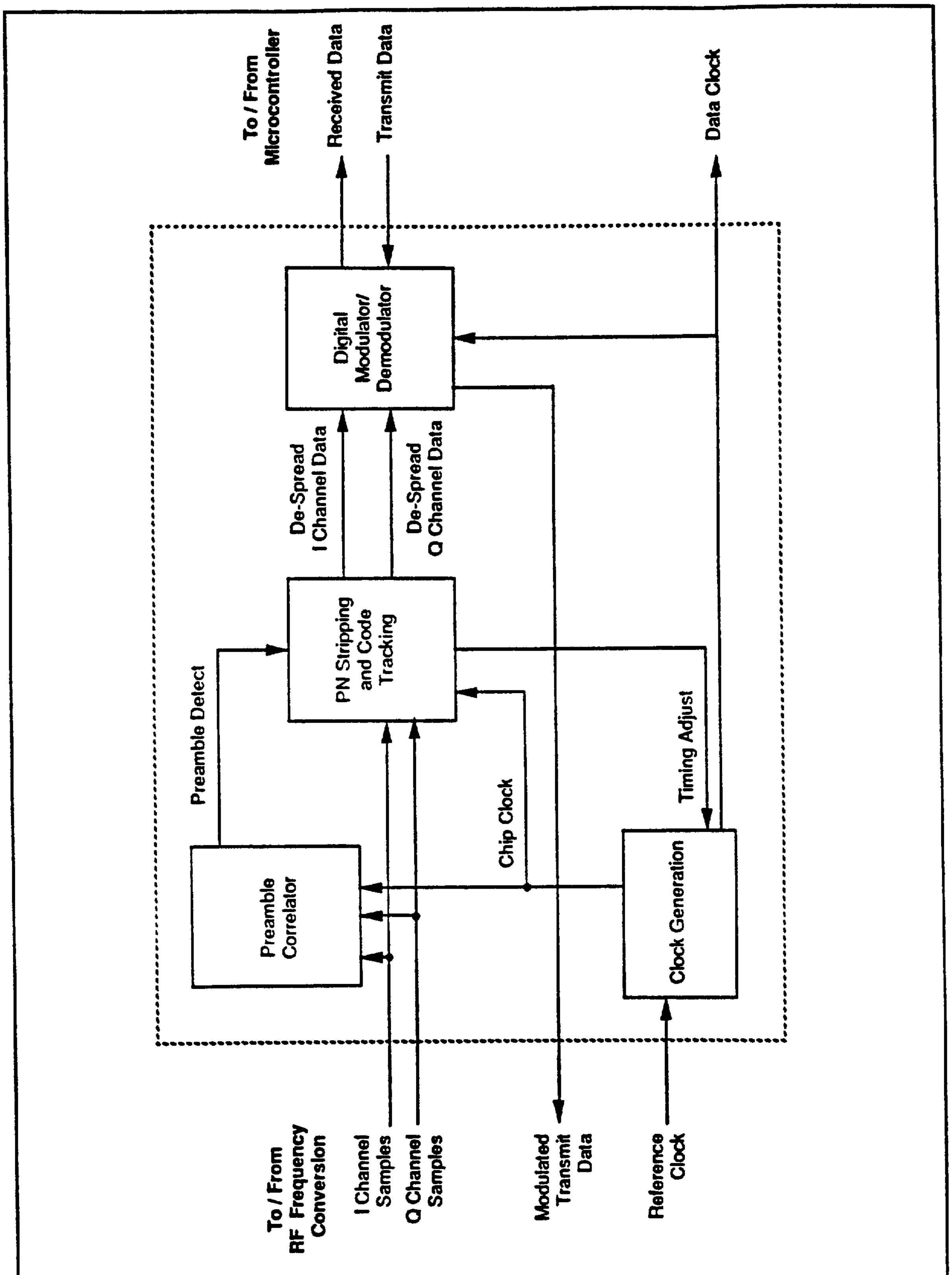


Figure 9.4 Block Diagram of the Digital Correlator Processor.

The PN stripping and code tracking circuit refines and maintains timing to within +/-1/8 of a chip period using an early-late gate tracking loop. This loop uses time delayed and advanced versions of the reference chip sequence to create an error signal which corrects the spread spectrum code clock. This precise timing is needed to minimize timing losses in the receiver to less than 1 dB.

The de-spread data is fed to the demodulator circuit. This circuit takes the I and Q channel samples, now at the data rate (after PN stripping and integration), and performs differential phase shift keying (DPSK) demodulation. DPSK demodulation is performed in two steps. First, the data is transformed from rectangular coordinates (I and Q) to polar coordinates (radius R and phase 0) . The second step is to compare the phase angle between successive bits and decode the data. Under differential modulation, a 0o phase difference decodes to a “zero”, a 180^0 difference to a “one”.

The clock generation circuitry consists of a synthesizer and divider chain. It is locked to the microcontroller’s 1.2288 MHz reference. The data and chip clocks are generated from this common reference. The ability to adjust the clock timing is provided by using a programmable divider that can lengthen or shorten a clock period by l/8 of a chip period

In aansmit mode, data is input from the microcontroller and differentially encoded in the modulator/demodulator block. Each encoded data bit is then spread (multiplied) by the fixed 32-bit PN chip sequence. The result is a modulated chip stream at 4.9152 MHz. This is output to the RF frequency conversion circuitry for upconversion and modulation onto the 420 MHz carrier.

9.4 MICROCONTROLLER CIRCUIT DESCRIPTION

The microcontroller performs overall control of the IVSAWS transceiver. Microcontroller functions include message generation, decoding, and processing, protocol and timing control, driver interface processing, and radio mode control. Figure 9.5 shows the components that make up the microcontroller. All of these components will be integrated into a single integrated circuit with the exception of the 32 KHz timer crystal.

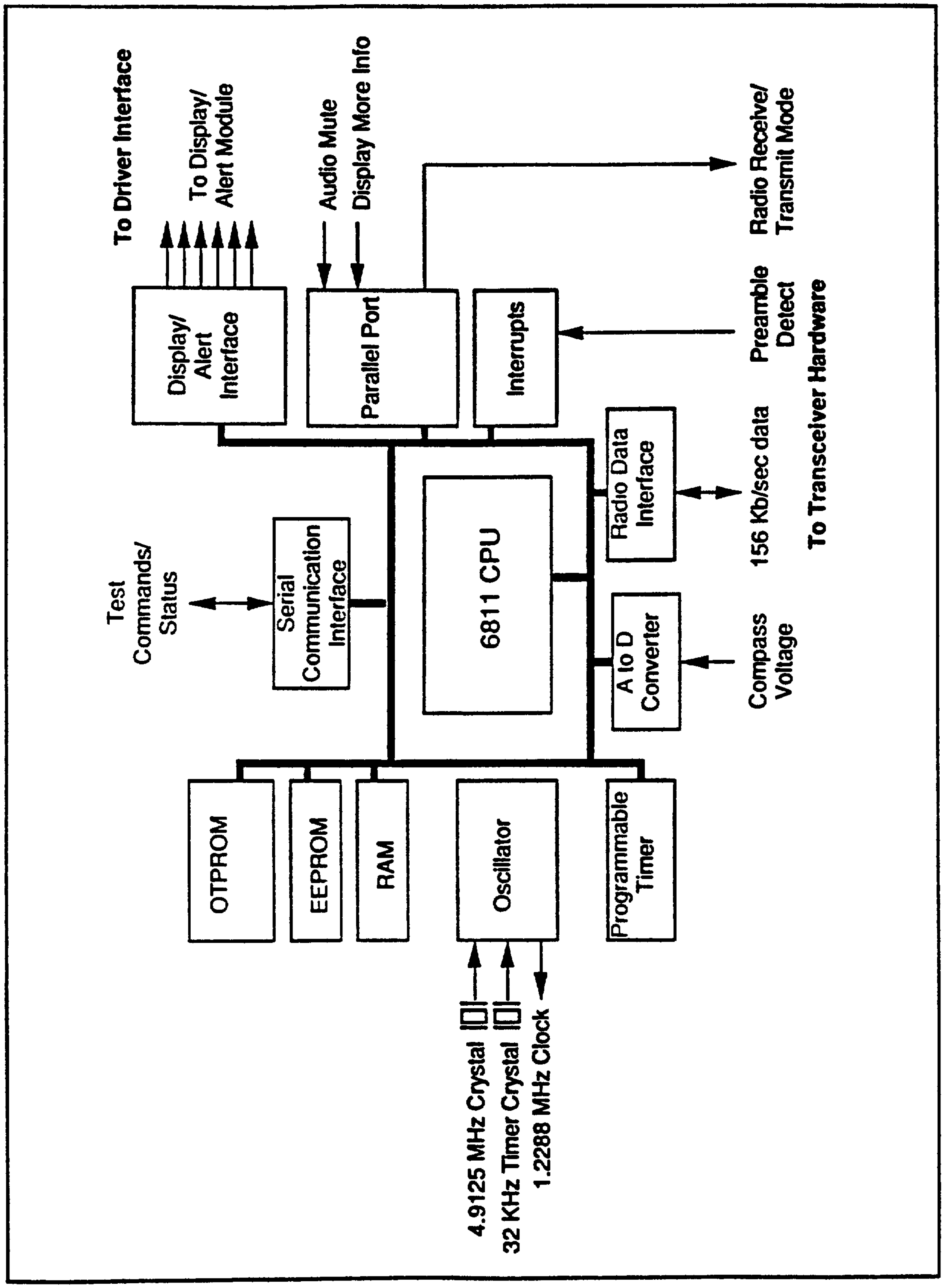


Figure 9.5. Block Diagram of the Microcontroller Circuit.

Because the microcontroller is a computer, its function is determined by the software it is running. The flowcharts of Figure 9.6a, Figure 9.6b, and Figure 9.6c give the basic processing steps that the vehicle unit microcontroller will execute. Upon power-up (Figure 9.6 a) the microcontroller sets the transceiver into receive mode and wait for an incoming start-of-message (preamble) to be detected When the preamble is detected, the transceiver digital hardware interrupts the microconuoller. The microcontroller then starts buffering the incoming 156.3 KHz data stream into microprocessor memory. The message is checked for bit errors by computing a CRC checksum and comparing it to the checksum included in the received message. If the two agree, the message is processed further acccording to the message type.

A hazard message is processed by first checking the message ID (Figure 9.5b). If that particular hazard has already been fully processed (two range measurements to the warning unit), the message is discarded and the transceiver returns to the message preamble search mode. If the message is not a duplicate, the valid heading field is decoded and compared with the vehicle's current heading. If the vehicle is heading in a direction that needs to be warned of the hazard, processing continues, otherwise the transceiver returns to message preamble search.

To respond to a valid hazard message, the vehicle unit microcontroller sets the transceiver hardware to transmit mode. The vehicle unit microcontroller has a pre-programmed range probe message that it always sends in slot 0. It times this transmission based on the reception of the hazard message. If no response is received to the slot 0 transmission, then it sends the same message in a randomly selected slot (l-512). A timer must be started following transmission of the range probe, so when a response is received round trip timing can be computed. This round trip timing is used to compute range to the warning unit

When a range response message is received (Figure 9.5c), the microcontroller first checks the message's vehicle ID. If there is a match, the message is processed, otherwise it is discarded The microcontroller computes its range based on the round trip time from its prior range probe transmission. If this is the second range message, speed is also computed. The microcontroller then computes the time to display the hazard to the driver based on the computed range, vehicle speed, and the hazard type. This will actually be a distance from hazard computation which is converted to a delay time based on speed and range. When the display time delay is elapsed, the driver display/alert is activated, and the transceiver returns to initial state.

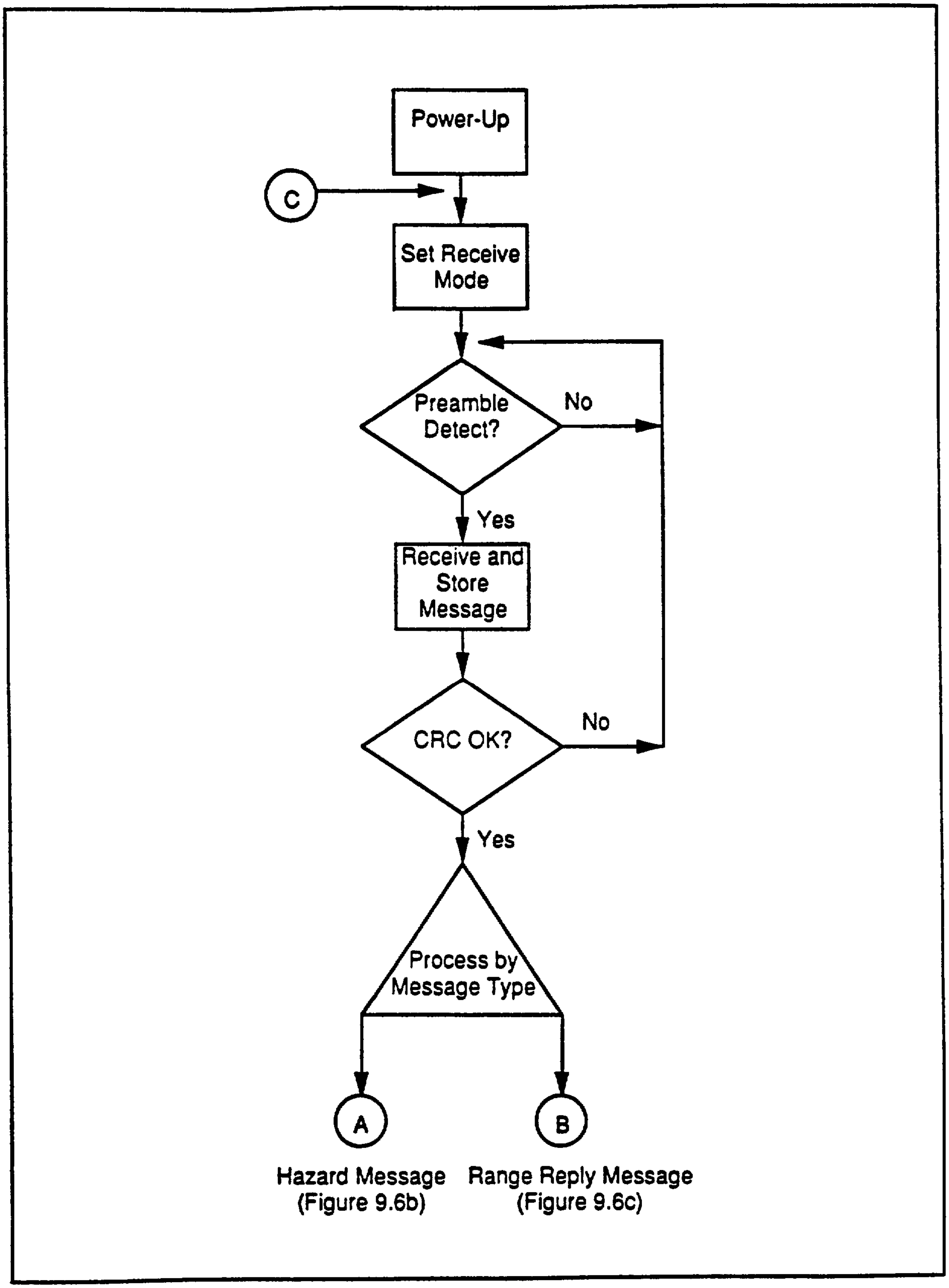


Figure 9.6a. Microcontroller Power Up and Message Reception.

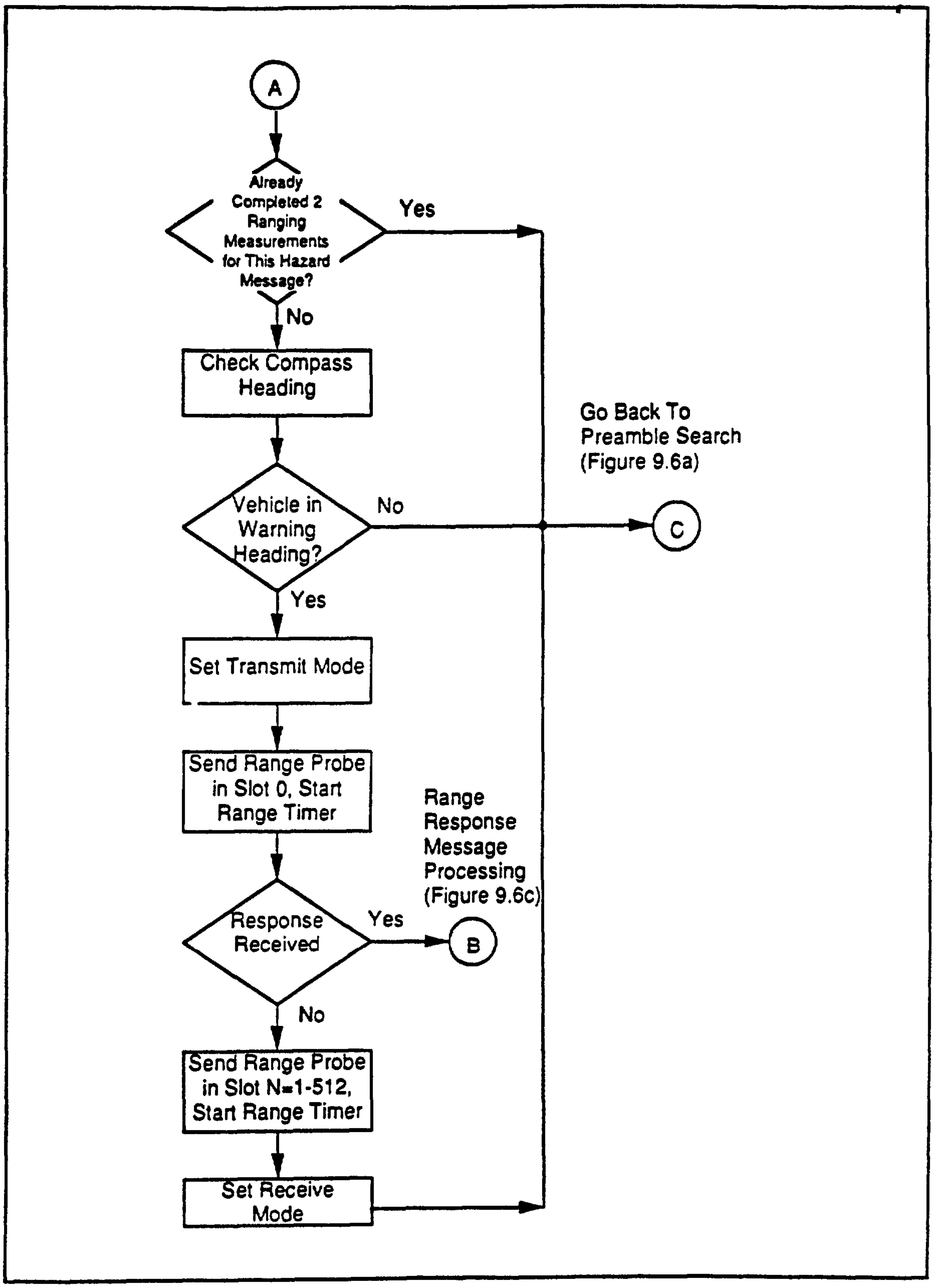


Figure 9.6b. Microcontroller Hazard Message Processing.

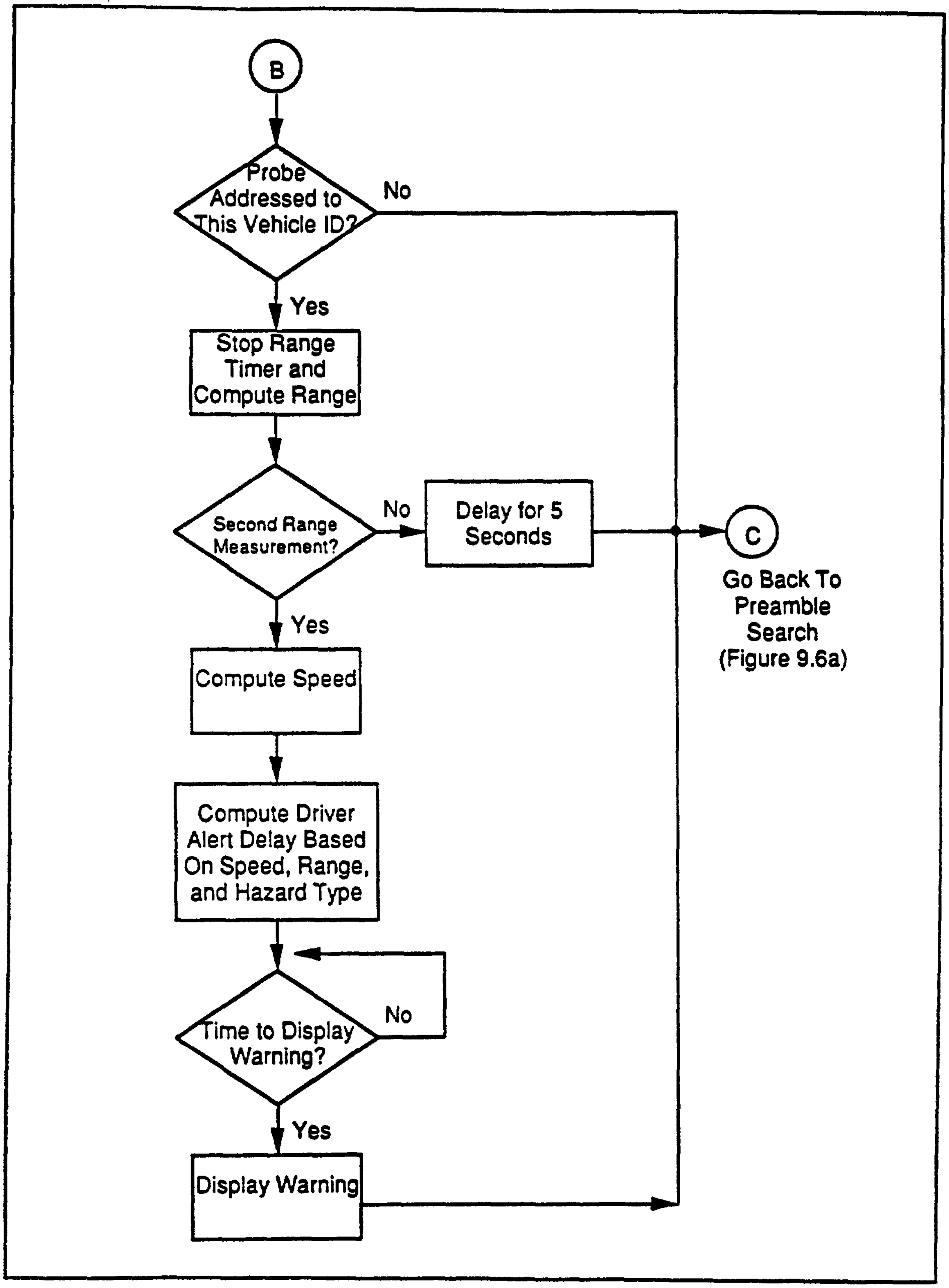


Figure 9.6c. Microcontroller Range Response Message Processing.

9.5 POWER SUPPLY CIRCUIT DESCRIPTION

The power supply differs with a vehicle or warning installation. A vehicle has 12 VDC (nominal) available from the battery. A warning unit in a permanent installation will use 110 VAC prime power, although portable or temporary warning units will require a battery powered option. If these portable units are based on 12 VDC battery power, a common power supply circuit can be shared with the vehicle units.

The majority of the radio circuitry, particularly the digital logic, requires 5 VDC. While the entire radio could be designed for 5 VDC operation, the power amplifier will be more efficient when operating at a higher voltage. Less current will be required from the 5 VDC supply. Since 12 VDC is available, it will be provided to the power amplifier, while the remainder of the circuitry will use 5 VDC. Figure 9.7 provides a block diagram of the power supply section. A vehicle application will use only the DC to DC converter, while a permanent fixed site installation could also include the AC to DC convener. Battery powered applications will use a small DC to DC converter, which accepts 12 VDC, divides it in half using a simple capacitive divider, then linearly regulates it down to 5 VDC using a low dropout regulator. AC powered units will include an AC to DC convener module, which will step down the input to approximately 10 VAC, then rectify and filter it to produce a raw 12 VDC which can be supplied to the other converter module.

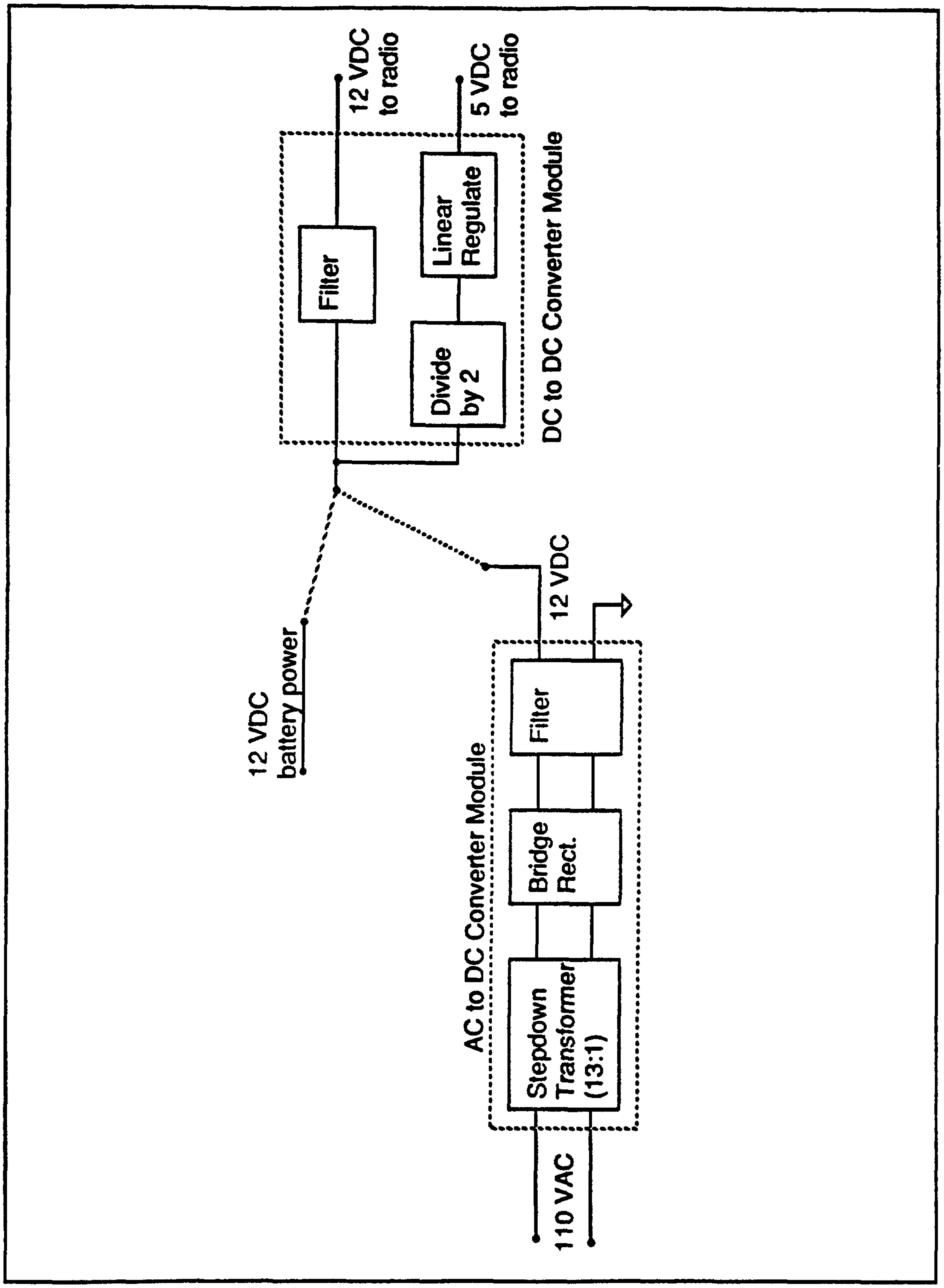


Figure 9.7. Block Diagram of the Power Supply Circuit.

10.0 IVSAWS Hardware Implementation and Cost Estimates

10.1 Overview

The IVSAWS radio is designed to exchange hazard and ranging messages between a warning unit and a vehicle unit. The IVSAWS radio is comprised of three major subassemblies — the Radio Frequency Circuitry, the Digital Correlator Processor, and the Microprocessor. The block diagram for the warning unit is provided for reference in Figure 10.1 These three subassemblies and their functional operation were described in Section 9 of this document. In this section, the hardware implementation approach is described. Parts lists and projected cost estimates are also provided for this hardware approach.

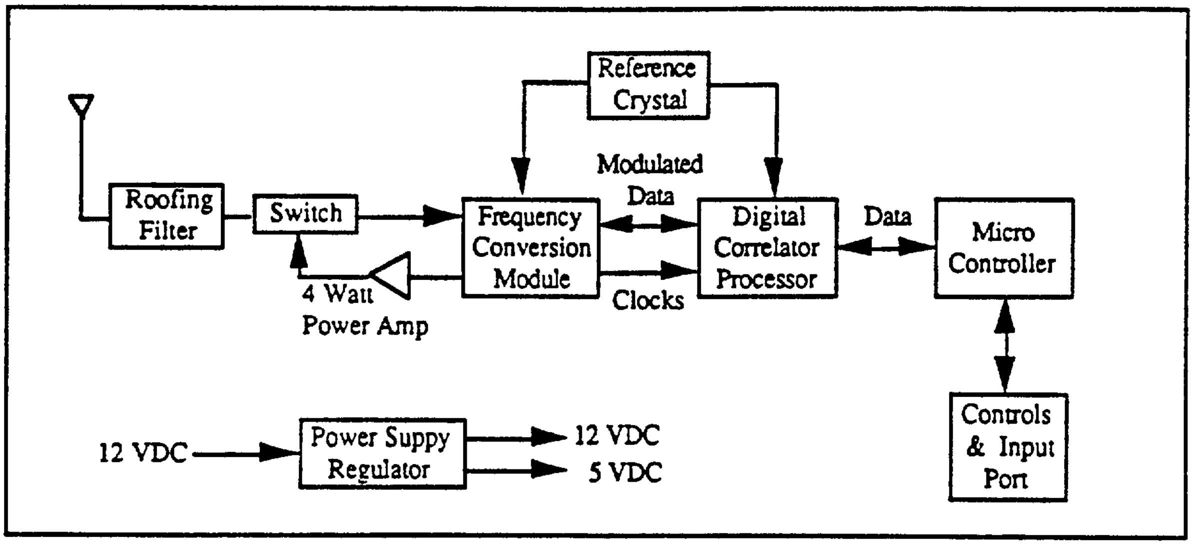


Figure 10.1. Block Diagram for IVSAWS Warning Unit.

10.2 Radio Frequency Circuitry

The radio frequency circuitry, like the remainder of the IVSAWS system, must be inexpensive to produce in volume production. This implies a minimum number of parts in the design since, as a general rule, assembly costs rise in proportion to the number of different parts that must be purchased, stored, and handled.

Ideally all the RF circuitry would be fabricated onto a single integrated circuit as proposed for the digital correlator processor or the microcontroller. Unfortunately, RF circuitry does not enjoy the same degree of standardization or integration capability as digital CMOS circuitry. Circuit designs vary widely with the function required, the power level, and the amount of gain, and invariably are custom layouts since routing can be critical for a stable circuit. Analog circuitry frequently requires resistors and capacitors, items which can be incorporated into an integrated circuit but which consume a significant amount of space. Finally, even when space is available, the number of functions must sometimes be limited, such as in an amplifier chain, where too much gain will result in a part that is unstable.

The dotted boxes in the block diagram of Figure 10.2 indicate where integrated circuits are planned for the transceiver. All of these parts are either currently available or represent minor modifications to existing designs that would not impact their cost when procured in volume. A parts summary is provided in Table 10.1.

Levels of integration higher than that listed above can be achieved, at some increased level of risk and cost. However, since the parts list is extensive, implying a high parts count design, further discussions with various circuit fabricators would be advisable when production plans for the radio are finalized. In particular, the synthesizer could be integrated into a single device. These are currently available, but at a significantly higher cost than the separate parts listed. As high frequency analog integrated circuit technology matures (especially if driven by volume production), prices will fall.

Gain profiles for the transmit and receive modes are presented in Figure 10.4. The receive circuitry accepts a signal at -100 dBm and, through the process of amplification and down-conversion, raises it to a 5 dBm signal level when input to the analog-to-digital converters. (5 dBm power level at a 100 Ω impedance level, $\pm$ 1 volt signal level) The transmit gain profile begins with the second local oscillator, at a power level of +10 dBm, which is mixed by the digital data. After several mixing and filtering losses, the signal is boosted by an amplifier chain up to a 4 watt (+36 dBm) transmit power level.

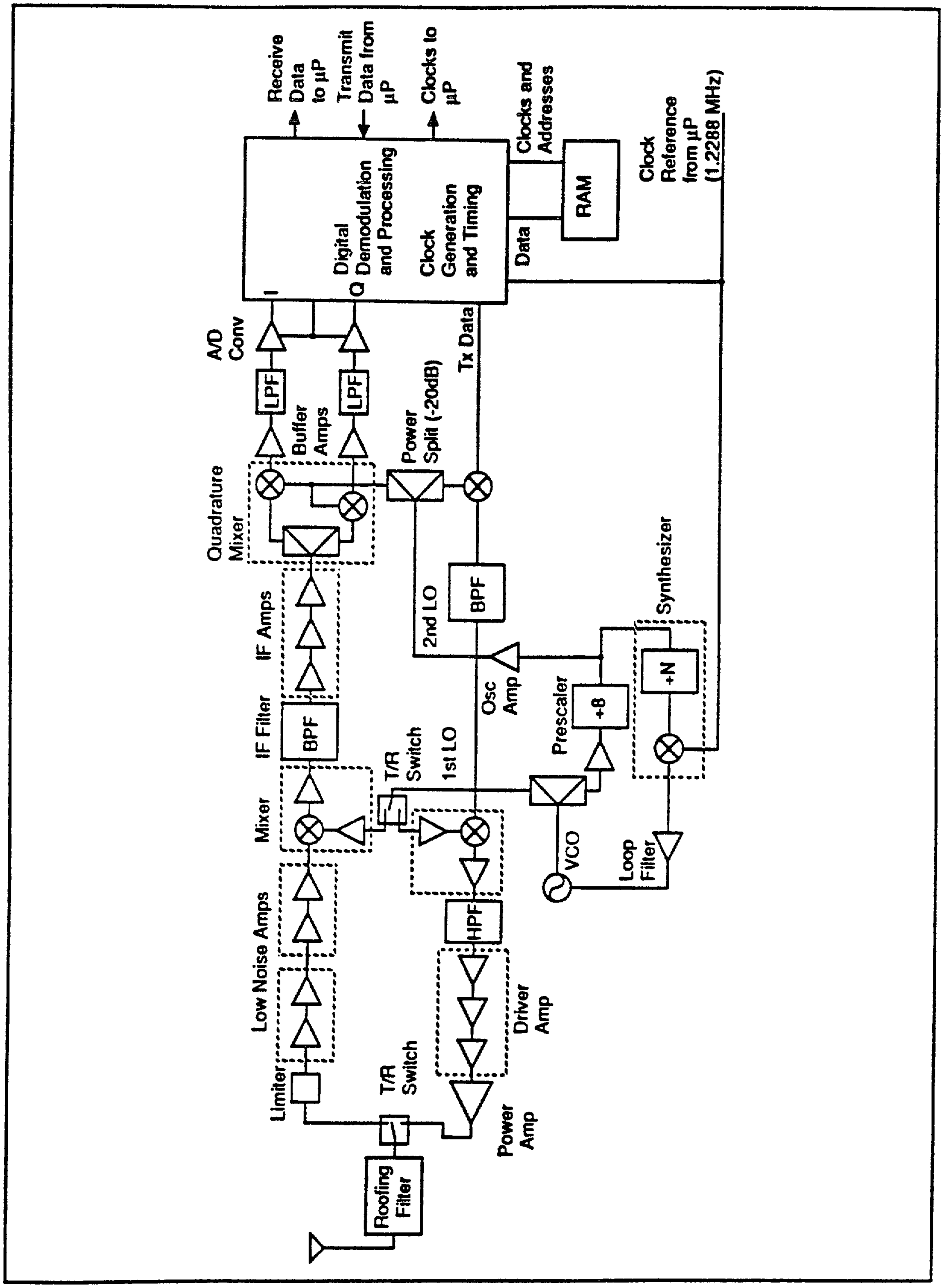


Figure 10.2. Detailed Block Diagram of the IVSAWS radio, emphasizing the RF circuitry.

Table 10.1. IVSAWS Radio Frequency Preliminary Pam List.

Part	Comments	Est. Cost* each/total	Vendor
Receive Circuit			
Roofing Filter	Lumped element microstrip design, with discrete L's and C's, 1 dB insertion loss	$0.20	Various
T/R Switch	Discrete component , .5 dB loss (2 places)	$1.25 / $2.50	Minicircuits
Limiter	Discrete component (unless integrated onto LNA)	$0.15	Various
LNA	Integrated multistage amplifier with low noise figure, 20 dB gain (2 places)	$4.00 / $8.00	Avantek
Active Mixer	Integrated design using Gilbert cell mixer, with amps for additional gain on LO and IF ports (2 places), 15 dB gain (RF and IF port), 0 dB LO drive level	$6.50 / $13.00	Avantek
IF Filter	Surface acoustic wave design, 15 dB loss	$7.00	Sawtek, Japanese vendors
IF Amplifier	Integrated multistage limiting amplifier, 60 dB gain maximum, -10 dBm limit level	$4.00	National
Quad Mixer	Hybrid package with power splitter on IF and LO ports, dual diode ring balanced mixers, 10 dB loss, +10 dB LO drive level	$3.50	Minicircuits
Low Pass Filter	Lumped element design, .5 dB loss (2 places)	$0.15 / $0.30	Various
Buffer Amplifier	Integrated device, 25 dB gain (2 places)	$1.50 / $3.00	Various
A/D Converter	Integrated device, 4 bit design (2 places); dual 2-bit converter very feasible as a custom design	$0.75 / $1.50	RCA
Transmit Circuit			
Power Splitter	Discrete component, second output at -20 dB with respect to input level	$0.90	Minicircuits
Mixer	Hybrid package, diode ring balanced mixer used for 2nd LO transmit mixing, 6 dB loss	$3.70	Minicircuits
Bandpass Filter	Lumped element discrete design, used for matching, 3 dB loss	$0.20	Various
Highpass Filter	Lumped element microstrip design, 1 dB loss	$0.20	Various
Driver Amplifier	Integrated multistage amplifier, 32 dB gain	$3.80	Motorola
Power Amplifier	Discrete design, 5 watt power transistor, 10 dB gain	$5.50	NEC, Toshiba
Synthesizer			
Volt. Cont. Osc.	Hybrid device, +5 dBm output power	$4.00	Murata
Power Splitter	Discrete component, equal outputs	$0.90	Minicircuits
Prescaler	Integrated circuit, divide by 8	$1.65	Motorola, Plessey
Program. ÷N	CMOS integrated circuit	$1.42	Motorola
Loop Filter	Integrated operational amplifier	$0.36	Various
Oscillator Amp.	Single stage amplifier, +10 dBm output power	$0.75	Fujitsu
	Total	$66 53	

Cost estimates based on 100,000 purchase quantities in all tables.

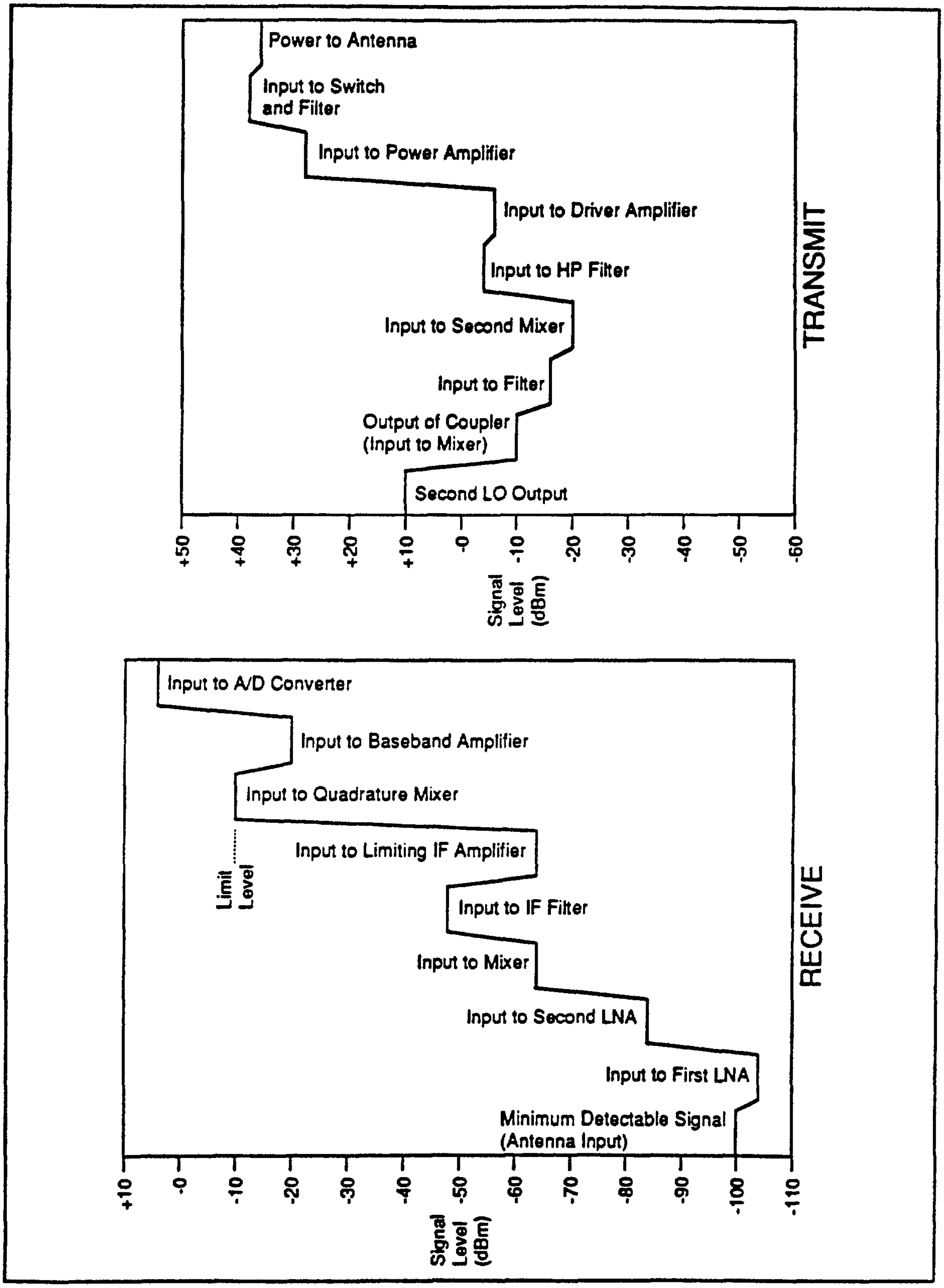


Figure 10.4. Gain Profiles of IVSAWS Transceiver.

10.3 DIGITAL CORRELATOR /PROCESSOR

All circuit functions in the DCP operate at a frequency of 40 MHz or less. These frequencies are well within the state of the art for VLSI implementation using CMOS technology. Current CMOS processes use geometries in the 0.8 to 1.5 micron range. Thus, an extremely high number of fast, low power digital gates can be incorporated onto a single device. The limiting factor in CMOS Very Large Scale Integration (VLSI) implementation of this type is die **size.** The defect rate is proportional to chip area. Hence as the gate count and resulting chip area grows, the probability that the circuit will be bad also increases. Yield reduction and cost increase are directly related to die size. Current gate array technology can provide gate counts in excess of 100 K gates, albeit with the yield and cost risks just described. Combining all these factors means that **CMOS** VLSI circuits with gate counts less than 20,000 equate to very low risk procurement and therefore low cost devices.

The goal is to have the entire DCP circuit as one low power, low risk, low cost, Application Specific Integrated Circuit (ASIC). To assess the feasibility of this goal, a gate count estimate for the DCP was performed. As the first step, the DCP functions were partitioned into 4 lower levels — preamble correlation, clock generation, PN stripping & code tracking, and digital demodulation. These 4 lower level functional block diagrams are shown in Figure 10.5a through Figure 10.5d. Accurate gate counts could then be reasonably estimated for each of these lower level functions. In Figures 10.5a through 10.5d, the numbers next to each of the boxes indicate the gate estimates for implementing that function. As shown in Figure 10.5a the DCP will also use standard generic RAM in addition to the ASIC The resulting gate estimates from these four lower levels are summarized in Figure 10.5e and Table 10.2.

The gate count summary shows an estimate of about 20,000 gates (80,000 transistors) for the DCP circuitry. This is well within the state of the art in CMOS VLSI technology. Hughes has experience with comparable demodulator designs that have gate counts exceeding 50,000 gates. A 10,000 to 20,000 gate design is routine technology today. The processing rates have been kept as low as possible for each circuit block so the power consumption of the DCP will be quite modest. CMOS circuits tend to be most efficient at low operating speeds. In summary, an ASIC implementation of the majority of the DCP circuitry is not only feasible, but is the preferred approach for this function.

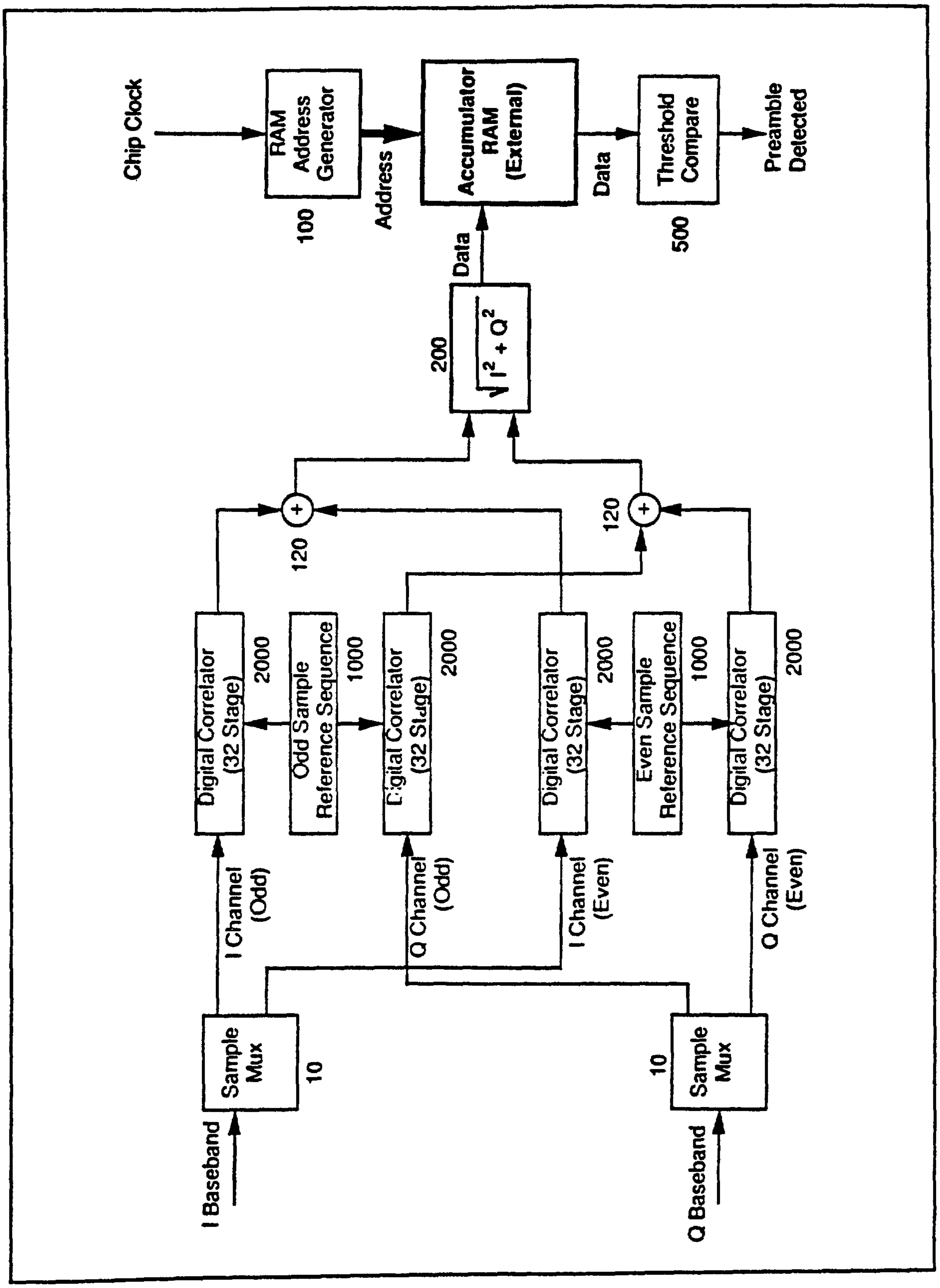
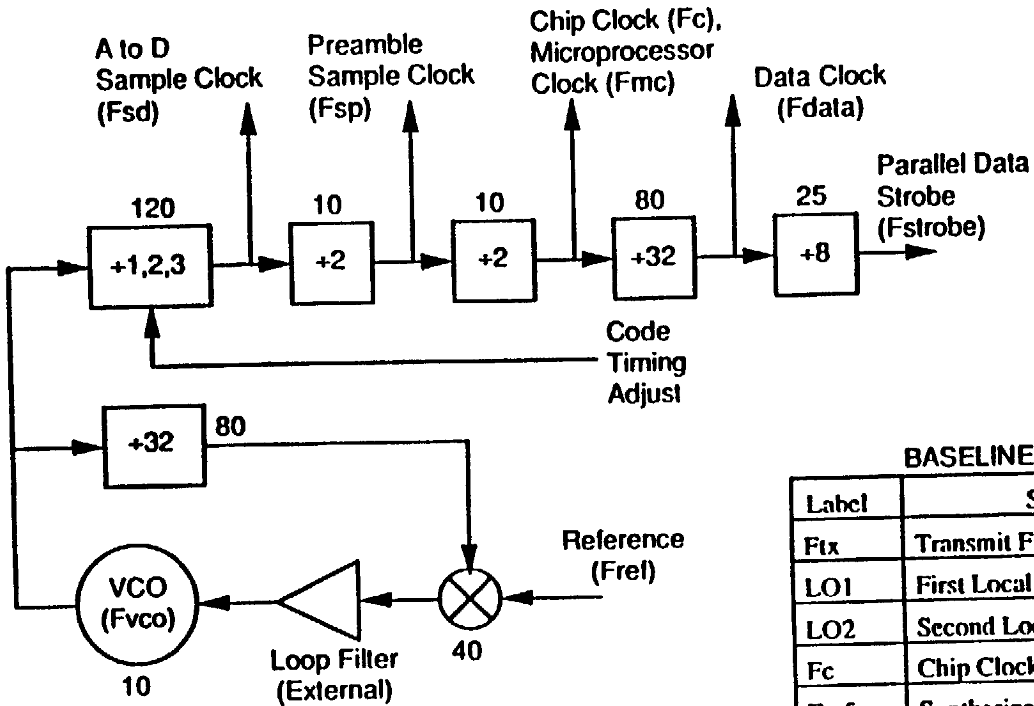


Figure 10.5a. Preamble Correlator Function in the DCP.



BASELINE FREQUENCY PLAN

Label	Signal	Baseline Value
Ftx	Transmit Frequency	420.2500 MHz
LO1	First Local Oscillator	372.5600 MHz
LO2	Second Local Oscillator	46.6900 MHz
Fc	Chip Clock	4.9152 MHz
Fref	Synthesizer Reference	1.2288 MHz
Fmc	Microprocessor Clock	4.9152 MHz
Fdata	Data Rate	153.6000 kHz
Fstrobe	Parallel Data Rate Strobe	19.2000 kHz
Fsd	A to D Sample Clock	19.6608 MHz
Fsp	Preamble Sample Clock	9.8304 MHz
Fvco	Digital Timing Loop VCO	39.3216 MHz

Figure 10.5b. Clock Generation Function in the DCP.

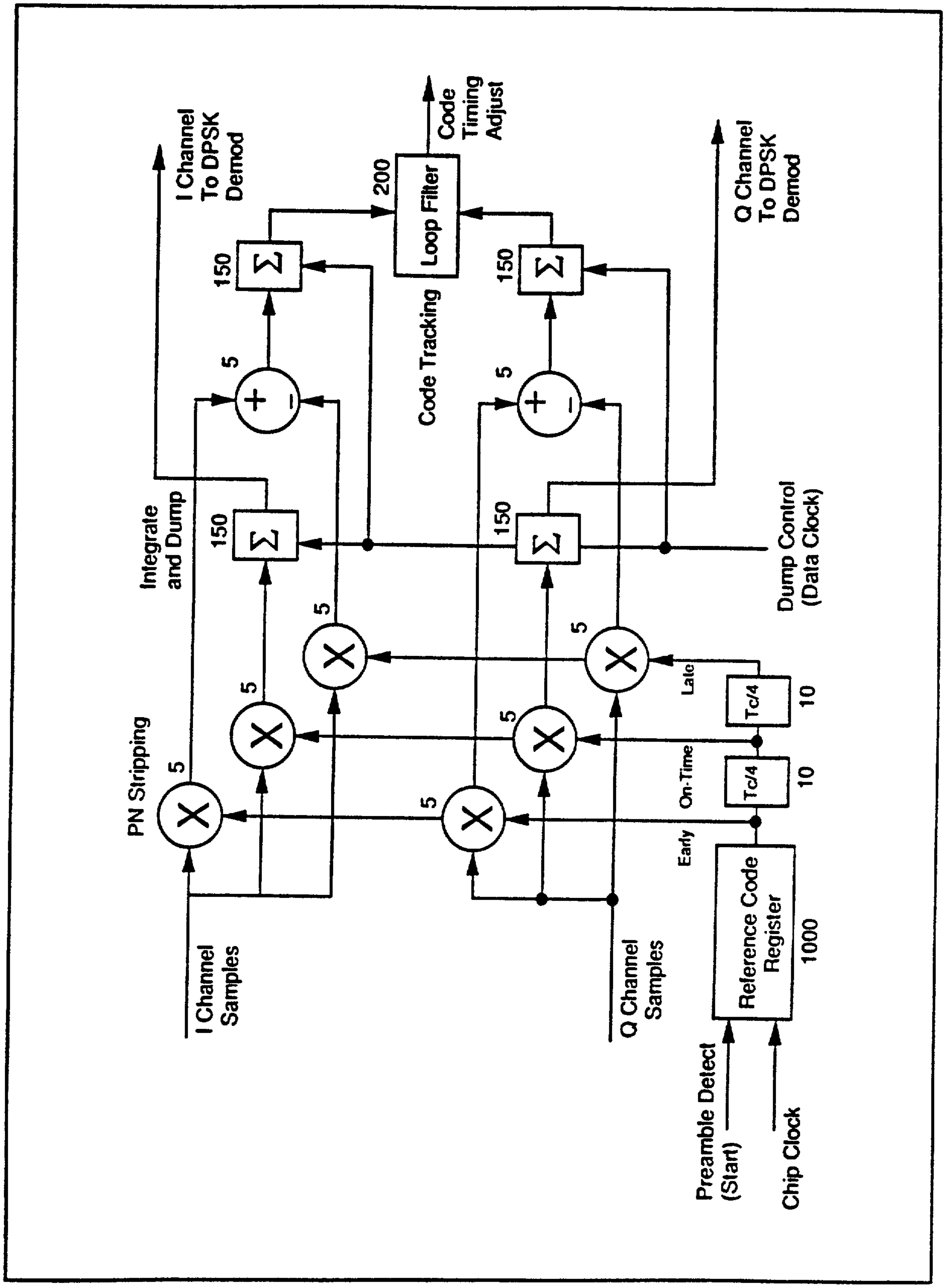


Figure 10.5c. PN Stripping and Code Tracking Function in the DCP.

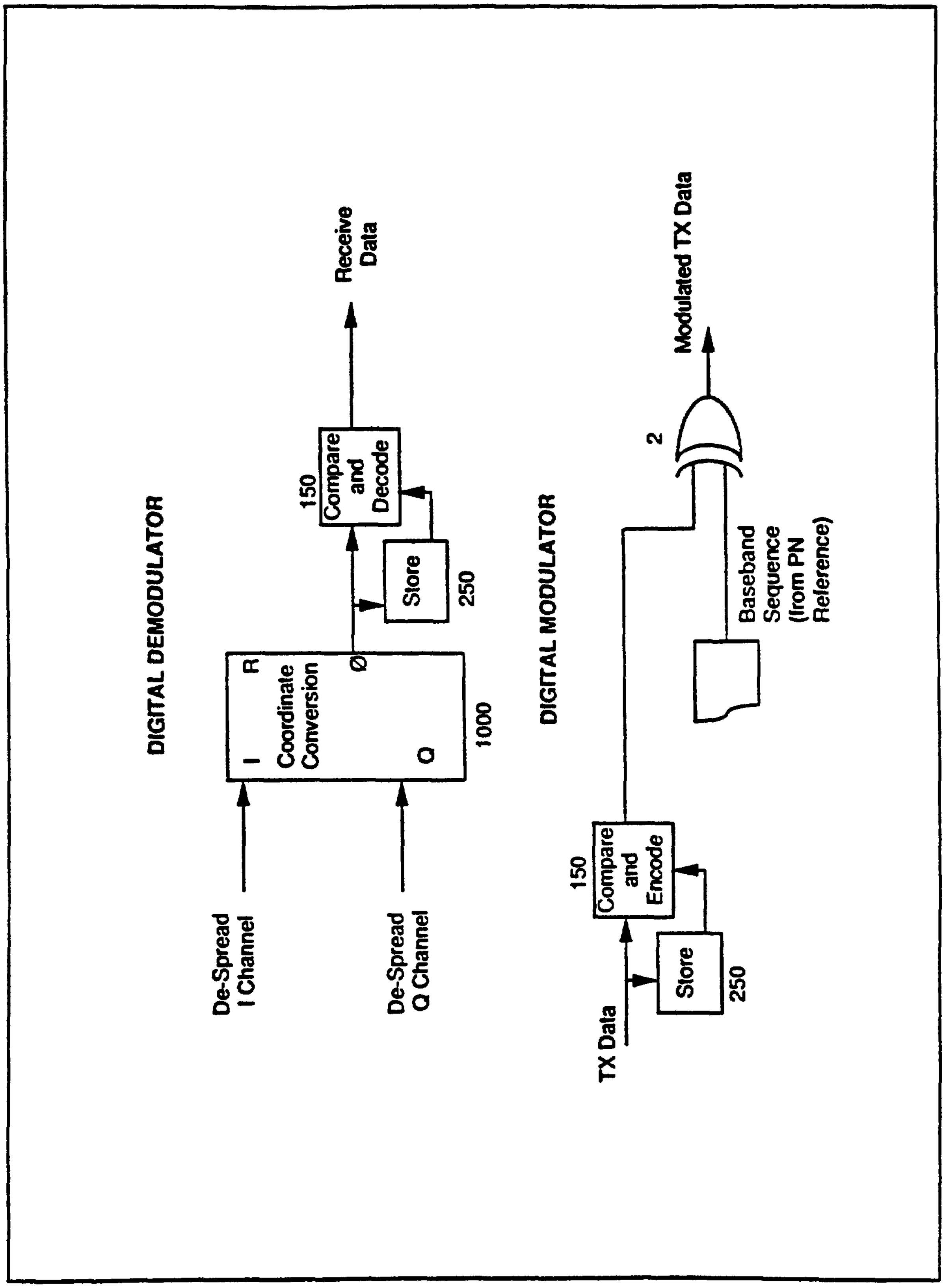


Figure 10.5d. Digital Modulator / Demodulator Function in the DCP.

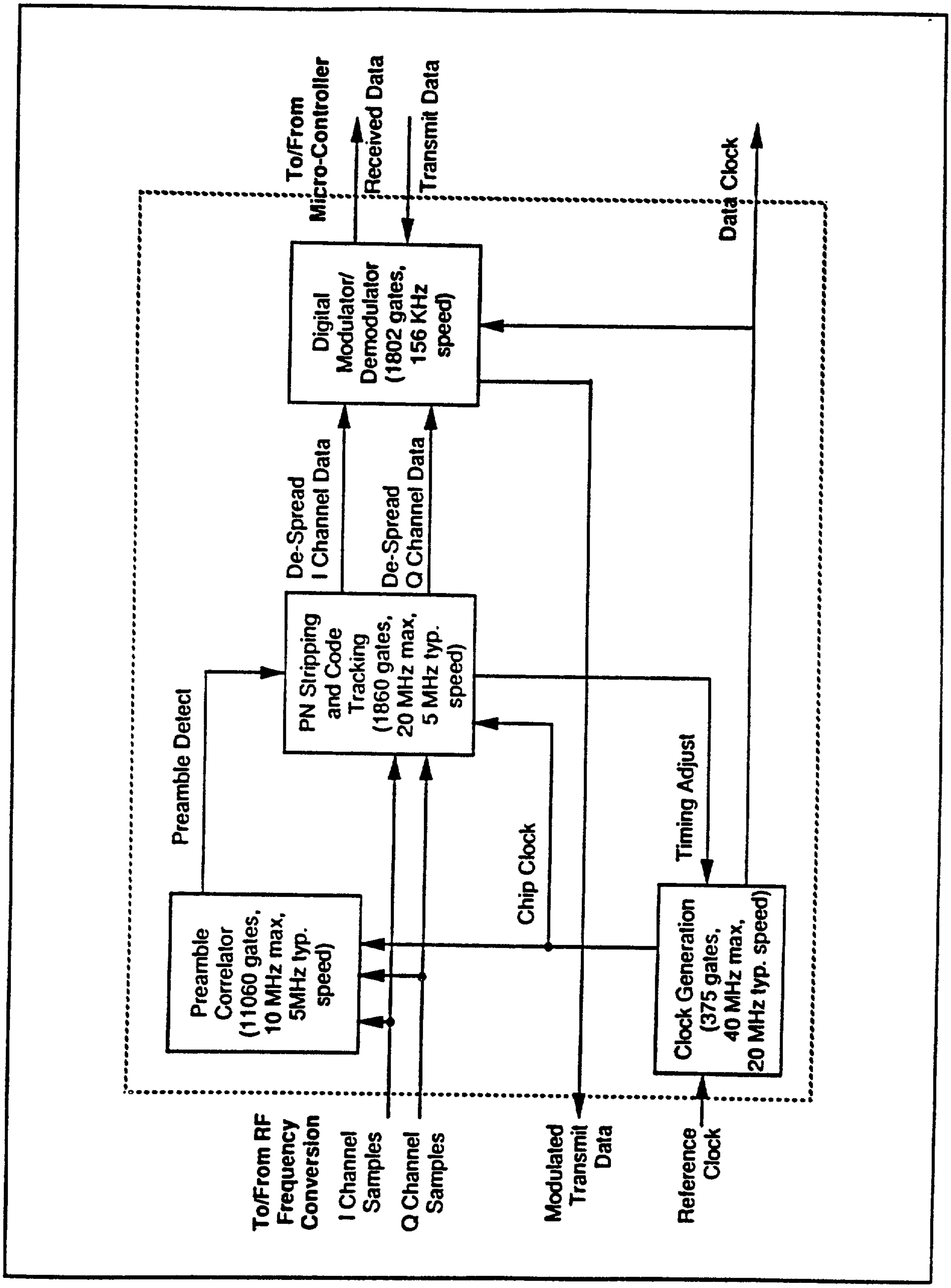


Figure 10.5e. Digital Correlator Processor with Summary of Gate Count by Function.

Table 10.2. Digital Correlator/Processor Gate Count Estimates

Circuit Function	Gates[1]	Effective Execution Speed[2]	Power Consumption[3]
Preamble Correlator	10820	5 MHz	0.25 Watts
PN Stripping and Tracking	1860	5 MHz	0.05 Watts
Digital Modulation/ Demodulation	1800	156 KHz	≤ 0.01 Watt
Clock Generation	375	20 MHz	0.01 Watt
Subtotal	14855		≤ 0.26 Watts [4]
Built in Test Circuitry at 30% of active gates	4455		
Total	19310		≤ 0.26 Watts [5]

[1]Equivalent 2 input NAND gates. A gate requires 4 transistors.
[2]Effective speed includes design considerations to lower speed. For example the preamble correlator is designed with 2 sets of correlators which are multiplexed, so each set operates at half speed.
[3]Assumes 50% gate toggling, 5μW/gate/MHz, bulk CMOS technology.
[4]The preamble correlator and PN Stripping and Tracking circuitry do not operate simultaneously.
[5]Built-in-Test circuitry will not operate unless in test mode. This would occur only during factory test and at power-up.

Because an ASIC implementation for the majority of the DCP functions, the DCP parts list contains just the ASIC, some RAM, and capacitors. Table 10.3 presents this preliminary parts list for the DCP portion of the radio. Because the final design is not completed and the complexity of the circuit is not absolutely known, an estimate has been made of the price based on the preliminary gate count.

Table 10.3. IVSAWS Preliminary Parts List for the Digital Correlator / Processor.

Part	Comments	Est. Cost each/total	Vendor
Correlator/ Processor	Custom CMOS digital integrated circuit	$10.00 (est)	Various
Memory	Static random access memory, CMOS integrated circuit, 64 (min) x 8 organization, 80 nsec access time	$5.00	Various
Capacitor	Power supply bypassing, ceramic	$0.05/ $0.15	Various
	Total	$15.15	

10.4 MICROCONTROLLER

The heart of the microcontroller is a 68HCll microprocessor. This is an 8-bit microprocessor commonly used for automotive applications because of its low power consumption. It has several low power modes including "wait" and "stop" modes that can be used to keep power consumption minimized during a period of inactivity. The 68HCll is available with a wide variety of on-chip peripherals such as those required for IVSAWS

The 68HCll controller and its peripherals will be driven by clocks generated in the on-chip oscillator as shown in Figure 10.6. This oscillator uses a standard 4.9152 MHz crystal. This crystal will provide the reference for all of the transceiver clocks and local oscillators and will have a stability of +/- 40 parts per million to minimize losses during communications. This reference is output to the remainder of the transceiver as a 1.2288 MHz clock, which is also used in the 68HCll. A second crystal (a 32.768 KHz clock crystal) will be used by the programmable timer when the processor is in a wait mode to track real time. The wait mode will be used to conserve power in between activities. This wait mode is especially critical for the battery powered permanent and temporary deployments of the warning unit

Three types of memory are available and desirable for the 68HCll processor. One-time programmable read only memory (OTPROM) will be used to store the software program and any look-up tables. This memory is can be programmed once on an assembled microcontroller. This is an advantage over designs requires ROMs that are "burned-in" during the semiconductor fabrication process, since upgrades to the software do not require a new microcontroller design. electrically erasable programmable read only memory (EEPROM) will provide a capability for non-volatile storage of variable data, even when the power is removed from the transceiver. This will be used for storage of ID codes, and, roadside unit for storage of the hazard message. Random access memory (RAM) will be used for temporary storage of received messages and for scratchpad computations if needed.

The programmable timer peripheral will be used to set time delays for the above described protocol. The peripheral can provide timing to within 1/32768 of a second and can time events up to 16 seconds in duration. This peripheral will not be used for range timing, since this requires precision to within 200 nsec (one chip period at 4.9125 MHz). This timing will be performed in software.

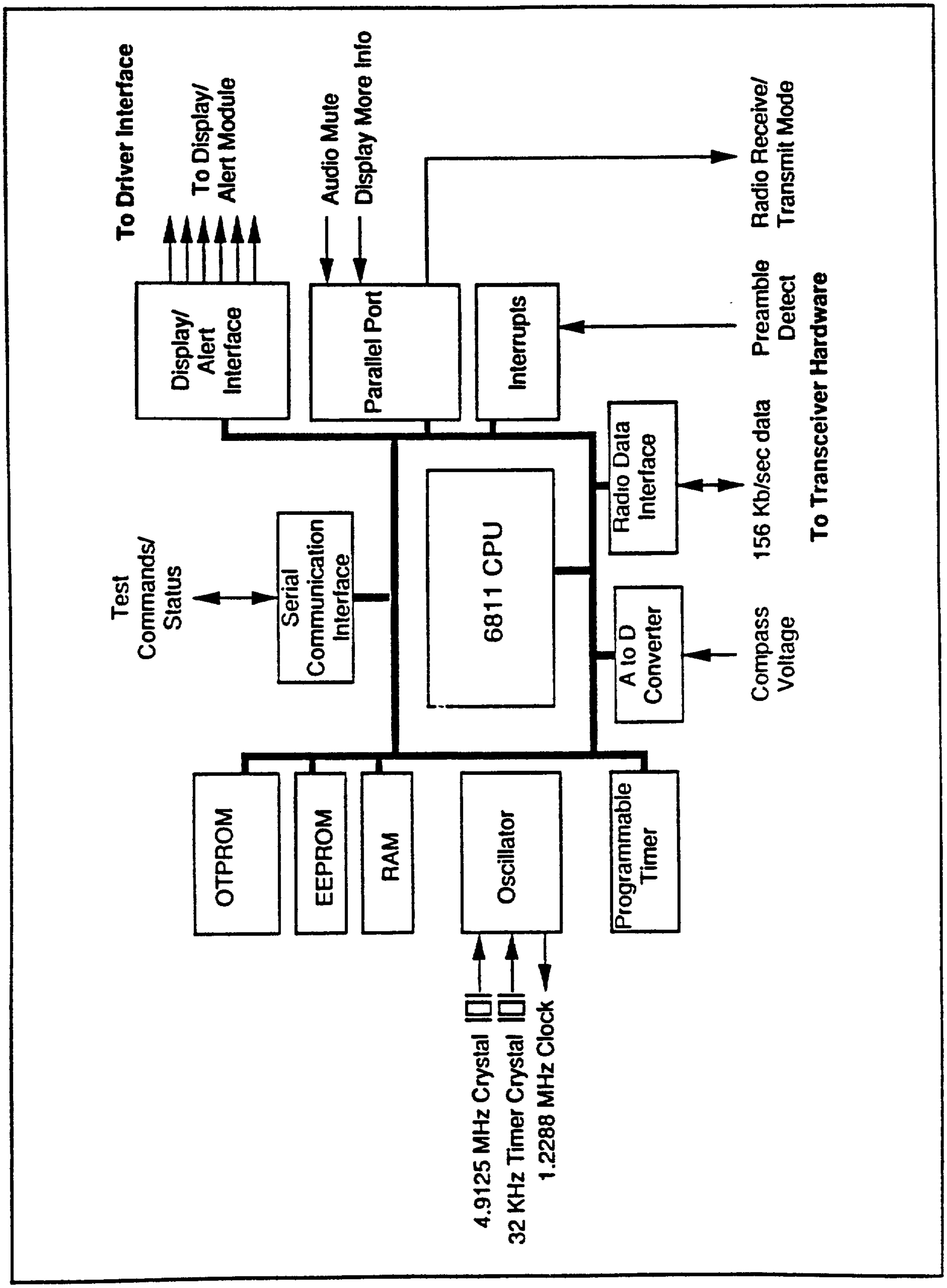


Figure 10.6. Block Diagram of the Microcontroller Circuit.

The microcontroller has three primary interfaces: to the operator through a display and controls, to the electronic compass, and to the remainder of the uanscciver via data and control signals. The radio data interface is at 156.3 KHz, or 19.2 Kbytes/sec. The radio data interface converts serial data at 156.3 KHz from the transceiver hardware and converts it to parallel bytes that are then processed at 19.2 KHz The electronic compass will output an analog voltage proportional to heading. An analog-to-digital converter peripheral will convert this to an 8-bit word for processing by the 68HCll. The display interface will provide the text characters, icon codes, and audio alert codes to the driver interface for presentation to the driver.

An interrupt handler peripheral processes the preamble detect line from the transceiver hardware and register it with the 68HCll. An 8-bit parallel port provides dedicated control or status lines to the transceiver and driver interface for mode control. Driver controls are shown for muting the audio and for calling up the full hazard message. These controls may be eliminated if the display interface is given the processing capability.

All microcontroller circuitry can be implemented on a single integrated circuit. Motorola, the vendor for the 68HC11, has a customer specified integrated circuit (CSIC) family of microconuollers, in which exact peripheral configuration are tailored to customer specifications. CSIC is not a custom design in the usual sense because all peripherals are already designed and the custom aspect is really only in the layout and interconnect of the peripherals with the 68HCll. Motorola also has a large number of off-the-shelf configurations. The 68HC7 1 lE9 configuration has everything needed for IVSAWS (and more). Depending on cost and power consumption considerations, this part could be used as is or in a trimmed-down version. The 68HC71 lE9 comes in a 52-pin plastic Ieadless chip carrier package that is suitable for automated surface mount assembly. Power consumption with a 4.9152 MHz crystal is 20 mW in the normal running mode, and 10 mW in the wait mode, and only 500 uW in the stop mode.

Table 10.4. Preliminary Parts List for the IVSAWS Microcontroller.

Part	Comments	Est. Cost each/total	Vendor
Microcontroller	68HC11E9	$10.00	Motorola
Crystal	4.9152 MHz frequency	$0.50	Various
Crystal	32.768 KHz frequency (clock crystal)	$0.50	Various
Capacitor	Power supply bypassing (2 places)	$0.05/ $0.10	Various
Display	40 character by 4 line, with drivers, uP interface	$10.00 (est)	Various
Compass	Electronic flux gate sensor, 16 directions (min)	$20 00 (est)	T.B.D.
	Total	$ 21.10 + compass	

10.5 POWER SUPPLY CIRCUIT

A vehicle installation will operate from the 12 VDC automotive battery using a DC-DC power converter. A passive filter will provide "clean" 12 VDC power to the radio (primarily for the power amplifier), while a DC-DC converter will reduce the 12 VDC input to 5 VDC to power a majority of the radio circuitry. A divider is used to efficiently reduce the input voltage by 2. High conversion efficiency is required to maximize battery life for vehicle or roadside applications where battery replacement or recharging is infeasible or difficult

The parts list in Table 10.5 assumes a vehicle unit contains only a DC-DC converter whereas a warning unit has both a DC and an AC power option, requiring an additional AC-DC converter. The divider portion of the DC-DC convener could be eliminated for those applications where power conversion efficiency is not a major concern (automobiles where the battery is constantly recharged). Eliminating the divider saves its costs but then the regulator must be upgraded to handle the higher power dissipation due to the increased voltage drop (7 VDC).

Table 10.5. Preliminary Parts List for the IVSAWS Transceiver Power Supply.

Part	Comments	Est. Cost each/total	Vendor
DC-DC Converter			
12 V Filter	Lumped element L and C design	$0.35	Various
Divider	Discrete components, 3 electrolytic C's, 4 P-MOSFETs, 1 N-MOSFET, 1 CD4049	$1.30	Various
Regulator	Low dropout, 3 terminal regulator (5 V, .5 A)	$0.25	Various
Output Capacitor	Electrolytic capacitor	$0.15	Various
AC-DC Converter			
Transformer	Isolation with single 10 VAC secondary and 10 VAC primary	$2.50	Various
Bridge Rectifier	4 diode integrated circuit, (.5A continuous)	$0.25	Various
Output Capacitor	Electrolytic capacitor	$0.15	Various
	Total (Vehicle/Warning)	$2.05 / $4.95	

10.6 MECHANICAL HOUSING

The primary IVSAWS operator interface (vehicle applications) is a small display screen. This could be incorporated into the front of the radio housing and a dash mount location found for the radio, similar to AM/FM receivers used in vehicles. An alternative solution uses a cable between the unit and the display, allowing nmote location of the radio in an under dash, under hood or trunk location. If the IVSAWS and entertainment radios share a common antenna, then antenna lead access would dictate an under dash location. Since this is the baseline design, the IVSAWS enclosure has been planned as a stamped steel housing with the appropriate connector.

Table 10.6. Preliminary Parts List for the IVSAWS Radio Assembly.

Part	Comments	Est. Cost each/total	Vendor
Housing	Shell, metal, top and bottom	$1.00/ $4.00	Various
Gasket	Shielding	$0.30	Various
Label	FCC & ID	$0.10	Various
Connector	PCB Mount	$0.50	Various
Antenna Coupler	Splits signal between IVSAWS and AM/FM radio	$2.00	Various
Wire Harness	To/from display, vehicle power	$0.50	Various
	Total	$8.40	

10.7 SUMMARY

The cost of a vehicle radio, in quantities of 100,000, is estimated to be $113.23 each. As indicated in the tables, prices of some items are estimated because parts suppliers of the exact items were not identified. The compass is an example. Rices on other items, such as the display, are changing regularly in response to pricing pressures in the commercial marketplace. Assembly cost is not included. Assembly costs would vary widely depending on the country of manufacture and degree of automation used.

Table 10.7. Cost Estimate Summary for the IVSAWS Radio.

mem	COST
Radio Frequency Circuitry	$ 66.53
Digital Cotrelator / Processor	$ 15.15
Microcontroller	$21.10
Compass	TBD
Power Supply	$ 2.05
Mechanical Housing	$ 8.40
TOTAL	$113.23

11.0 IVSAWS RADIO RELIABILITY ASSESSMENT

The preliminary parts list from the radio implementation task were used to arrive at an assessment of the reliability of the vehicle transceiver. The following assumptions were used:

1. The transceiver will be mounted under the dash within the passenger compartment. Rubber bushings will be used in the mount.
2 The transceiver is powered only when the key is turned on.
3. The transceiver is built with commercial parts.
4 Military Handbook-217F was used as the source of failure data.

Failure rates were first calculated for the various subassemblies of the transceiver. Table 11.1 summarizes the failure rate results.

Table 11.1. Failure Rate Assessment

CIRCUIT FUNCTION	FAILURE RATE (per hour)
Receive Circuit	$7.64 \cdot 10^{-6}$
Transmit Circuit	$5.36 \cdot 10^{-6}$
Synthesizer	$5.93 \cdot 10^{-6}$
Power Supply	$4.31 \cdot 10^{-6}$
Digital Correlator/processor	$1.61 \cdot 10^{-6}$
Microcontroller	$5.27 \cdot 10^{-6}$
Housing Parts (incl wire/connector)	$1.10 \cdot 10^{-6}$
LCD Display	$2.46 \cdot 10^{-6}$
TOTAL FAILURE RATE	$33.68 \cdot 10^{-6}$

This failure rate corresponds to a mean time between failures (MTBF) of 29,690 hours. This is 3.4 years of continuous operation. If a vehicle, when operating, is assumed to travel at an average speed of 20 mph over its lifetime, it will take 5,000 hours to accumulate 100,000 miles. This is a reasonable average over a large vehicle population. If an individual vehicle were to go 200,000 miles, the 10,000 hours incurred would still be well under the MTBF rate predicted for the IVSAWS radio. If the transceiver were to be mounted in the trunk instead of a dash location, the increased temperature extremes and vibration would drop the MTBF to an estimate of 10,560 hours — still adequate for most vehicles.

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APPENDIX A

SPECTRUM AVAILABILITY FOR IVSAWS

[In general bracketed bold type is used to denote editorial remarks or sections requiring review.]

A.1. INTRODUCTION

[The one subject I have not included in the Introduction is a discussion of minimum power requirements. If this isn't discussed in other sections of the report, it would be useful to include a discussion here.]

As a recent report by the National Telecommunications and Information Administration (NTIA in the Department of Commerce) emphasizes, there is a growing need for radio spectrum "as the demand for existing spectrum-based services grows, and new spectrum-related technologies and applications emerge."[1] IVSAWS (and indeed all of IVHS) are one of the "new spectrum-related applications" that will require access to the radio spectrum.

The safety related nature of IVSAWS makes the task of obtaining a spectrum allocation more difficult. Given the crucial nature of IVSAWS communications, the probability of interference from other radio services must be kept very low. As discussed elsewhere in this report, the use of spread spectrum techniques will reduce the likelihood of interference but it is not a complete solution. While an exclusive allocation to IVSAWS will probably not be required, other co-channel users will have to be carefully regulated to insure minimal interference. Thus, many bands with existing users, are not promising candidates for IVSAWS use because of the high cost of removing existing, incompatible users.

While IVSAWS can be a stand-alone system, its value to the driver will be much larger, and the costs lower, if IVSAWS is part of a larger IVHS. Thus, spectrum availability for both a stand-alone IVSAWS and for IVSAWS as part of IVHS are discussed below.

Three key assumptions underlie this analysis. They are:

- That a single national channel was desired, and that while state-wide channels might be acceptable, any system that operated on multiple channels, with local constraints on which channel any particular transmitter could use, was unacceptable.
- That while a wideband channel (~1 MHz) was desirable, narrow-band channels (25-50 kHz) were not excluded from consideration.

1 U.S. Spectrum Management Policy: Agenda for the Future, NTIA Special Publication 91-23, February 1991, p. 1.

- Widespread implementation of an IVSAWS system will require a change in FCC rules, since there is no current provision in the FCC rules that meets the full requirements of an IVSAWS system. Given the potential importance of IVSAWS to the American public, this analysis assumes that the FHA, state and local governments, private industry, and representatives of the driving public would be jointly petitioning the FCC to amend the rules to provide provisions for IVSAWS. Even with such a wide basis of support, it is still likely that there will be significant opposition to the rule changes necessary for IVSAWS. While such judgements are necessarily subjective, this analysis has tried to restrict consideration to options that have a substantial prospect for acceptance, assuming widespread support for the IVSAWS proposal.

The next section of this spectrum analysis summarizes the most likely candidates for meeting the needs of the IVSAWS program. Following that, the details of the options for full IVHS accommodation are discussed in the third section. In the fourth section the suitability of several bands between 800 and 1000 MHz for either a stand-alone wideband or narrowband IVSAWS is explored. In the fifth section the suitability of bands below 800 MHz is explored. In the final section (6) the ability to use Part 15 (unlicensed operation) for IVSAWS is explored. Comments are also made about the suitability of particular bands for the initial testing of IVSAWS.

A.2. OVERVIEW OF SPECTRUM AVAILABILITY RESULTS

Tables A2.1 and A2.2 summarize the key results of this study. The top section of Table A2.1 discusses the leading candidates for a narrowband system. There are three unallocated 1 MHz bands at 900 MHz with no currently licensed users. Two of the bands have been reserved for future land mobile use and the third was reserved for advanced paging systems. Given the absence of current (and often entrenched) users, it should be possible to obtain the reallocation of a small part (25-50 kHz) of one of these 1 MHz bands. The second set of viable candidates are the Low VHF (47 MHz) and High VHF (151-159 MHz) channels that are dedicated to the Highway Maintenance Radio Service (i.e. the two-way radios used by state and local government highway departments). While these channels are heavily used and there would be significant costs involved in reaccommodating the existing users, it should be possible to free one or two of these channels on a nation-wide basis for IVSAWS.

The second section of Table A2.1 discusses the leading candidates for a stand alone wideband IVSAWS system. The three unallocated blocks at 900 MHz are again conceivable. The advanced paging (930-931 MHz) band is probably the best candidate since it should be possible to share this band between IVSAWS and the new advanced paging systems proposed by the industry. An additional prospect is the band 420-422 MHz. This lies on the edge of an allocation for high power DoD radars. The FCC has already indicated that it might be willing to reallocate 420-421 MHz to a new service. Even without co-channel radars, very careful analysis would be needed to verify that IVSAWS could be safely operated adjacent to such high power radar systems.[2]

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2 Without the technical advantages of spread spectrum operation, it should be even more difficult to operate an IVSAWS narrowband system in this band. Hence, 420-422 MHz is considered a poor candidate for narrowband operation.

Table A2.1

LEADING CANDIDATES TO ACCOMMODATE IVSAWS

Band	Frequencies (MHz)	Current Allocation	Disadvantages
		NARROWBAND (25-50 kHz)	
900 MHz	901-902, 940-941	Land Mobile Reserve	Promised Service
" "	930-931	Advance Paging Reserve	Proposed for LEOs Promised Service
Low V	47.02-47.40	Highway Service	Must Reaccommodate Existing Users
High V	151-159	" "	
		STAND ALONE WIDEBAND IVSAWS (1 MHz)	
900 MHz	930-931	Advanced Paging Systems	Promised Users (paging) Proposed for LEOs
" "	901-902, 940-941	Land Mobile Reserve	Promised Service
UHF	420-422	DoD Radars	Adjacent to High Power Radars 420-421 Proposed for LEOs.
		WIDEBAND FOR IVHS (10-25 MHz)	
Permanent Above 1 GHz	From Executive Branch spectrum (3.1-3.7 GHz is a likely band) to be transferred to civilian use under proposed legislation.		
Experiments			
	1,350-1,400	Radar	25 states have no assignments.
	1,429-1,435	Military Fixed/Mobile	Only 133 assignments listed. Private Land Mobile already secondary.

Table A2.2

Optimistic Estimates of Allowable Spread Spectrum Power Available to IVSAWS System Operating in Bands Below 1 GHz

Band	Frequencies (MHZ)	EIRP	Other Problems
Part 15	902-928	4 w	No protection from high power interferers.
AM Broadcast	525-1705 kHz	150 nW	Very optimistic
Citizens	26.9-27.4	--	Too much interference in narrow band avail.
Highway Maint.	Low/Hi V	--	Too narrow band.
	UHF	--	No exclusive band.
General Land Mobile			
Low VHF	10 MHz BW	3 uW	
High VHF	10 MHz BW	64 uW	
UHF	10 MHz BW	147 uW	
Television	614-806	10 uw	Very optimistic
FM Broadcast	88-108	5 uW	Very optimistic
Cellular	[tbp]		
800/900	[tbp]		

Note: Many assumptions, etc., were used to make these estimates. They are discussed in the text.

The bottom section of Table A2.1 briefly summarize the prospects for a band wide enough to accommodate not only IVSAWS but an entire IVHS. There is very little prospect that a 10-25 MHz band could be found below 1 GHz. Even above 1 GHr would still be difficult under normal circumstances. However, as discussed below, there has been significant movement in Congress and in the Executive Branch to accomplish a reallocation of spectrum below 5 GHz from Government to Non-Government use.3 While there is significant uncertainty, there is a realistic prospect of obtaining a clear allocation sufficient to accommodate all (or most of) IVHS communications between vehicles and the local node. Pending action by the Executive Branch, exactly what bands below 5 GHz will be available is unknown. Table A2.1 identifies one likely candidate for permanent reallocation (portions of the 3.1-3.7 GHz radar band) and two bands that might be available for initial exploration of IVSAWS (1.35-1.4 and 1.429-1.435 GHz).

A significant number of bands below 1 GHz were explored for either a narrowband system or a spread spectrum system operating underneath the existing users. While in some cases frequencies could be identified that might be available for narrowband systems in certain areas, the desire for a nation-wide channel (and rquirement for a state-wide channel) ruled most of these bands out.

[Note that Table A2.2 needs to have two values (for Cellular and 800/900 Land Mobile]

As summarized in Table A2.2 spread spectrum systems operating underneath existing services could not use enough power, even under very optimistic assumptions as to the amount of interference they would be allowed to generate to the existing service. The detailed assumptions that underlie the summary results in Table A2.2 are discussed in the fifth section of this spectrum availability analysis. Without a careful review of these assumptions, readers should not treat these results as anything more than a rough indication of the viability of using a particular band.

Part 15 of the FCC rules allows for the unlicensed operation of equipment that meets certain technical standards. While operation under the provisions of Pan 15 would be very convenient, the analysis in Section 6 shows that it is not really practical. Except for the special circumstances of spread spectrum devices operating in three designated bands, the highest EIRP allowed a communications device operating under Part 15 is 18 mW and most operations are for far less4 While the provisions for Part 15 spread spectrum operation allow a 4 Watt EIRP, the high power transmitters already allowed in this band make it (in general) unsuitable for a safety related service such as IVSAWS. The analysis also shows that the FCC has sufficient flexibility to eliminate the need for burdensome individual paper licenses without requiring operation under Part 15.

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3 In the context of U.S. spectrum management, Government means Federal agencies who obtain their radio authorizations from NTIA (operating under delegated authority from the President, 47 U.S.C. 305 and Executive Order No. 12,046, as amended, 3 C.F.R. 158 [1971]). Non-Government includes state and local governments who receive their radio authorizations from the FCC (47 U.S.C. 301 & 303).

4 EIRP is Equivalent Isotropically Radiated Power and is the product of the power into an antenna and the gain of the antenna (relative to an isotropic antenna).

A.3 BANDS SUITABLE FOR IVHS

[Note, there is some repetition between the introduction to this section and the discussion in the proceeding section. If section 2 remains where I have placed it, i.e. it is not moved to an executive summary, etc., then some of this repetition should be removed.]

While IVSAWS can be a stand-alone system, its value to the driver will be much larger and the costs lower, if IVSAWS is part of a larger IVHS. Finding a frequency band that is large enough to meet the full needs of IVHS for communications between vehicles and local node is clearly harder than simply finding a band suitable for a stand-alone IVSAWS.[5] It would be very difficult to find the 10-25 [?] MHz that will be needed below 1 GHz. Even obtaining a band above 1 GHz would still be difficult under normal circumstances. However, there has been significant discussion in Congress and in the Executive Branch about reallocation of spectrum below 5 GHz from Government to Non-Government use. There are now three separate bills in Congress that propose to reallocate at least 200 MHz from Government to Non-Government use.[6]

While there is no certainty that any of these bills will be passed, there does seem to be considerable momentum towards some type of reallocation from Government to Non-Government to meet the needs of the emerging radio services. IVHS could easily be one of the new services which could benefit from this reallocation. Thus, it seems reasonable that IVSAWS may ultimately operate within a larger band with a primary allocation to highway/vehicle communications.'

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5 It is likely that an economical implementation of IVHS will also require spectrum for internode links, especially those connecting a local node to the regional center. Since this requirement is for fixed,long distance communications, finding suitable bands (if the existing bands in Part 94 are not adequate) is beyond the scope of this study.

6 S. 218 the Emerging Telecommunications Technology Art of 1991, 102d Cong., 1st Sess. 1991. and H.R. 531, the Emerging Telecommunications Technology Act of 1991. 102d Cong., 1st Sess. (1991) were written by members of the majority. H.R. 1407, 102d Cong., 1st Sess. (1991) is a revised version of H.R. 531 by members of the minority (it also states that the Government bands will be from below 6 GHz).

The President's FY 1992 Proposed Budget assumes that 30 MHZ of Government spectrum will be reallocated to Non-Government use.

7 While IVHS (including the IVSAWS application) does not automatically need an exclusive allocation, any sharing with other services (or for that matter between IVSAWS and other IVHS services) will need to be done very carefully, in view of the safety related nature of the IVSAWS communications, The spread spectrum nature of the proposed IVSAWS implementation should increase the opportunities for carefully controlled sharing.

Even if one of these bills were to pass, there is no certainty about which bands would ultimately be reallocated to Non-Government use, let alone which might be reallocated for IVHS use. One band that is a likely candidate for reallocation away from the Government is some portion of the 3,100-3,700 MHz radar bands. While this may ultimately prove to be the best band for IVHS (including an IVSAWS), it is not suitable for the initial IVSAWS system, given its current use for radar.

Two bands were identified from the US Table of Allocations that might be suitable for a wider bandwidth initial IVS AWS.8 These were 1,350-l ,400 MHz and 1,429- 1,435 MHz. The fist band, 1,350-l ,400 MHz, is allocated for radars in the Radiolocation and Aeronautical Radionavigation services. In addition, there are International Footnotes (7 18 and 720) urging the protection of radio astronomy and US Footnote 311 urges that assignments in this band be avoided near 13 observatories listed in the footnote. According to information developed by proponents of mobile satellite service, this band is lightly loaded in the US with only one international registration (for the Ratio Astronomy Very Large Array in New Mexico), 220 in the Government Master.Frequency File, and 13 in the FCC Master Frequency File. Further, there are 25 states with no assignments at all.9 Thus, it should be possible to use this band for initial IVSAWS operation in one of these 25 states that does not have radio astronomy operations in this band.

The primary allocation in 1429-1435 MHz is military fixed and mobile operations. Non-government users may use it on a secondary basis fo;btnd mobile telemetering and telecommand operations under section 90.259 of the FCC's Rules. Thus, it is likely that initial operation of IVSAWS would be allowed if a location without government assignments could be found. Since mobile satellite service proponents only found 115 assignments in the Government Master Frequency File and 18 in the FCC Master Frequency file it should be possible to find areas where initial IVSAWS operation would be allowed.

8 The US Table of Allocations (including the footnotes) is found in FCC rule 2.106 [47 C.F.R. section 2.1061.

9 Third Interim Report of Ad Hoc Group C of Informal Working Group 2 of the FCC Industry Advisory Committee on Preparation for WAX-92,"Mobile Satellite Services from 1 to 3 GHz," February 24, 1991, pp.14f, A-I-7, and A-I-28f. It is worth noting that the FCC in its Notices of Inquiry in Docket 89-554, has not proposed this band for reallocation to the Mobile Satellite Service.

10 Note that section 90.259 also permits private land mobile operation in the band 1427-1429,but operations in that band are also secondary to Space Operations (earth to space).

11 Third Interim Report of Ad Hoc C, supra, p. A-I-28.

A.4. CANDIDATE BANDS IN 800-1000 MHz

[I am assuming that you will expand this section to discuss other 800/900 MHz options. Especially spread spectrum underneath cellular, SMR, etc.]

Until recently, the FCC was able to meet the requirements for new mobile services from the band 800-1000 MHz. However, with three exceptions discussed below, this band is now completely allocated to specific services. Table A4.1 lists these allocations.

Narrowband

There are three unassigned non-government 1 MHz bands at 900 MHz. These are the two General Mobile Reserve frequencies at 901-902 and 940-941 MHz. Proponents of various forms of Personal Communications Services (PCS) have advocated the assignment of these bands for their service. Several experimental licenses have been issued for PCS experiments in these two bands.

930-931 MHz has been reserved by the FCC for advanced paging systems. Recently Telocator, the trade association for the paging industry, filed a Petition for Rule Making with the FCC proposing that the FCC assign this frequency for what Telccator described as "Advanced Messaging Services" (AMS).[12] One of the motivations for filing at this time may have been the proposal by the FCC in its WARC-92 Inquiry to reallocate 930-93 1 MHz for use by Low Earth Orbit (LEO) satellite systems.[13]

Since there are no existing licensees, or even applicants, for these three reserve bands, reallocation of a narrow portion of one of these bands to IVSAWS should be achievable. One of the two Mobile reserve bands, would probably be preferable, since it is likely that this band will be licensed in narrowband (land mobile) channels.[14]

As shown in Table A4.1 there are bands for Public Land Mobile at both 800 and 900 MHz. While essentially all of the land mobile channels have been assigned in the largest markets, it may still be possible, albeit with difficulty, to reallocate a channel or two to IVSAWS on a nationwide basis. As a practical matter it would be necessary to arrange for the reaccommodation of any existing users. If this option were seen as desirable, it should be quickly pursued. Given the pace of land mobile expansion, this option will become more difficult (and more expensive) with each month of delay.

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12 Telocator Petition for Rule Making, RM-7617, filed January 23, 1991.

13 Second Notice of Inquiry in General Docket 89-554 (Preparation for WARC-92 FCC 90-316, released 10/l/90), para. 82 The International Telecommunications Union has scheduled a World Administrative Radio Conference to be held in Spain from February 3-March 5, 1992 (WARC-92). Docket 89-554 is the mechanism by which the FCC obtains advice from the public on what proposals the FCC should recommend to the State Department for inclusion in the US position.

14 Since these two bands are already paired for two-way use, obtaining a paired set of channels for expansion of the IVSAWS to include return communications from vehicles should also be possible.

Table A4.1

U.S. ALLOCATIONS IN 800-1000 MHz

Band (MHZ)	SERVICE
614-806	UHF Television
806-824	800 MHz Private Land Mobile (Mobile)
824-849	Cellular (Mobile)
849-851	Aeronautical Public Phone (Gnd to Air)
851-869	800 MHz Private Land Mobile (Base)
869-894	Cellular (Base)
894-896	Aeronautical Public Phone (Air to Gnd)
896-901	900 MHz Private Land Mobile (Mobile)
901-902	General Purpose Mobile Reserve
902-928	ISM, Gov't Radars, Amateur, Part 15, etc
928-929	Multiple Address Svc (Remotes)
929-930	Paging
930-931	Advance Paging Reserve
931-932	Paging
932-935	Gov't Fixed
935-940	900 MHz Private Land Mobile (Base)
940-941	General Purpose Mobile Reserve
941-944	Gov't Fixed
944-960	Non-Gov't Fixed
960-1240	Aeronautical Radionavigation

While more difficult, it may also be possible to reallocate a narrowband channel from one of the other existing services in 800-1000 MHz, given that not all of these services have become fully loaded. This option probably makes sense only as a backup to the narrowband options discussed above.

Wideband

The most promising options for a stand alone wideband IVSAWS in 800-1000 MHz is the three reserve bands discussed above. The 930-93 1 nserve for advanced paging is the most promising for three reasons. First, since AMS would be a brand new service without any technical rules at present, there is more fexibility over the rules under which the other service (AMS) would operate. Second, it should be easier to develop an approach that allows IVSAWS and AMS to compatibly share the band 930-931 MHZ, since the Telocator Petition assumes that a wideband data signal would be used for AMS. Third, the potential of loosing this band to LEO or other services, may make the paging proponents more willing to adjust their operations to allow compatibility between AMS and IVSAWS, then they would normally be.

The two Land Mobile reserve bands (901-902 & 940-941 MHz) are also candidates, although arranging technical compatibility between the wideband IVSAWS and the (most likely) narrowband land mobile systems would be more complicated. Unless there are Government systems that could compatibly share with IVSAWS, none of the remaining bands in 800-1000 MHz are promising.

The difficulties with Part 15 operation in the band 902-928 MHz are discussed in Section A.6 Given the high power DoD radars in this band, and the complete absence of any protection criteria or procedure for existing licensed private mobile users, this band appears to still be unusable, even if IVSAWS were allowed in the band on a licensed basis.

A.5 CANDIDATE BANDS BELOW 800 MHz

Potentially promising bands below 800 MHz are discussed in this section from lowest to highest band. In several cases, "order of magnitude" calculations are performed to estimate the power that might be allowed to an IVSAWS spread spectrum signal under (optimistic) assumptions as to how much interference will be allowed to the existing service. The detailed assumptions behind these calculations are presented in indented sections.

Leaky Cable Systems in 510-1705 kHz

Narrowband

AM Broadcast Band: 535-1605 kHz (today)
535- 1705 kHz (planned)

Any feasible scheme for using the AM broadcast band cannot involve any interference to reception inside any AM station's service area. This would prevent co-channel, 1st and probably 2nd adjacent operation. Thus, no single channel is available on a nationwide basis, and it is unlikely that a single channel would be available on a state-wide basis in the larger, more populated areas. This rules out narrowband usage of the AM broadcast band.

Non-Broadcast: 510-535 kHz

There are at least three problems in using the frequency band 510-535 kHz. First, there are travelers information stations operating on 530 kHz Below this in the band 510-535 kHz, the US government operates aeronautical radionavigation systems, and 518 kHz is used for the international NAVTEX system in the Maritime Mobile service. Thus, the band 510-1705 kHz will not meet any of the requirements for a narrowband IVSAWS.

Wideband

A necessary (but not necessarily sufficient) condition for operating a spread spectmm system under AM broadcasting stations is that no perceptible interference be caused to AM broadcast reception. Very simple calculations show that the power available for such a system would be far below that needed by an IVSAWS, i.e./ an EIRP of less than 150 nW.

> FCC rule 73.37 requires that any new station's .005 mV/m contour not touch the .l mV/m contour of the existing station. Since the broadcasters are now trying to push for wider bandwidth receivers of 7.5 kHz, assuming that the victim receiver has only a 3 kHz IF bandwidth is again conservative. Thus, any IVSAWS spread spectrum system cannot put more than .005 mV/m into any 6 kHz. [16] Further, let us optimistically assume that this criteria would only need to be met 30 meters away from an IVSAWS transmitter. Using the far field relationship this would permit an EIRP of 750 x 10^{-12} W/6 kHz. [17] Extrapolating to the 1180 kHz in the band 525-1705 kHz, the total power allowed a broadband IVSAWS is only 150 nW.

Citizen's Band 26.9-27.4 MHz

Narrowband

Trying to keep non-emergency calls off CB channel 9 is, at best, difficult (impossible is probably closer to the truth). The prospect that operation on any other CB channel could be eliminated to allow NSAWS operation is simply non-existent.

Wideband

Even ignoring the serious interference that would be received by an IVSAWS receiver from a nearby CB transmitter, there is simply not enough bandwidth to spread the IVSAWS signal to prevent interference to CB reception. At 30 meters, the IVSAWS transmitter would

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15 See Footnote US 18 to the US Table of Allocations.

16 Note that these are clearly optimistic values, i.e. they tend to overestimate the amount of power that an IVSAWS system would be allowed. The 5 uV/m is probably high since FCC station spacing criteria are not intended to provide interference free service,but only limit interference to acceptable levels. The 6 kHz is probably low, in view of the pressure by broadcasters to have wider bandwidth AM radios.

17 While 30 meters is clearly not far field at this frequency, using the asymptotic limit will understate the field strength produced by this EIRP at 30 meters, i.e. less EIRP would actually be allowed.

create unacceptable interference to the reception of any CB signal whose range is greater than 240 meters. This high level of interference to CB operations would not be permitted.

> [The calculation given below, assumes that a 1W EIRP is needed. If about 1 mW, (26/900)2 is all that is needed, the R comes out 8.3 km, which isn't impossible. Wouldn't the interference situation to IVSAWS be impossible? That may be a better way of removing this option.]

> A 1 Watt IVSAWS signal would contribute 25 mW to each of the 40 CB channels. AM CB radio is allowed 4 watts of power. Assuming an antenna of 6 dBi, this is a 16 Watt EIRP. If one assumes that only a 10 dB C/I ratio is requred then *one* can use the far field relationship to determine the distance from the CB radio at which the power flux density of the CB transmitter is 10 times higher than the power flux (in a single CB channel) created by an IVSAWS transmitter at 30 meters.18

<u>Highway Maintenance Radio Service</u> (all bands below 800 MHz)

Under FCC rules in Part 90, private land mobile users are divided into different services based on the activity being carried out by the licensee. State and local governmental entities are allowed to use frequencies assigned to the Highway Maintenance Radio Service for communications "essential to official highway activities of the licensee" (FCC rule 90.23). In each of the land mobile bands below 800 MHz, certain radio channels are assigned to the Highway Maintenance Service. These stations are generally in one of three bands which are:

Band	Frequency Range		Number of Channels
Low VHF	45-48		25
High VHF	150-160	MHz	33
UHF	453-459	MHZ	38

On many of these channels there are certain restrictions or other conditions. The three most notable are that of the 25 low VHF channels, 20 are restricted to use by state highway departments, 15 of the 33 high VHF channels are restricted to local (i.e. non-state) govemmcnts, and that all of the UHF channels are shared with the other services in the Public Safety Radio Services (i.e. local government, police, fire and foresay/conservation). A few other channels are nor: included in the table given above because of more stringent restrictions on their use.

Narrowband

Given the affinity between the users of this service and FHA, obtaining exclusive use of one or more of the Highway VHF channels (High or Low) for IVSAWS is conceivable. Selection of a UHF channel may be more difficult since these channels are not exclusively used by highway related entities but are instead used by many other state and local governmental users. Even attempting to use a Low VHF or High VHF channel(s) till not be easy, because these bands are heavily used. As a practical matter it will likely be necessary for FHA to provide funding to reaccommodate the existing users of the selected channel(s) to other mobile radio channels.

18 Again, the far field relationship is probably not valid, but its use should tend to underestimate the interference that would be caused by an IVSAWS transmitter.

Reaccommodation Costs

This reaccommodation is more complicated than merely finding another channel. This is because in many cases a single radio channel is part of a "network" of other frequencies, either with other highway users or with related agencies, e.g. state police. Since mobile radios will only work in one of the three bands, it will normally be necessary to reaccommodate the users of the selected channel(s) within the same band. When this is not possible because of congestion, it may be necessary to move a whole "network" to another band.

Technical Considerations

Technically, these channels should be compatible with the requirements of IVSAWS. The adjacent channel restrictions in the high VHF band may cause a minor problem, but it should be resolvable. Section 90.205 allows transmitter powers of 300 watts or more. At both low and high VHF there are sets of channels where the Highway channels are contiguous. At UHF, all of Highway channels are separated from each other by a channel in the Local Government Radio Service.

The low VHF channels are on 20 kHz spacing, the high VHF on 15 kHz, and the UHF on 25 kHz spacing. The maximum allowed bandwidth for FM or PM of analog voice is 20 kHz [Section 90.209(b)(4)). The out-of-band suppression requirements are as follows [from section 90.209(c)(l)]:

% of Authorized Bandwidth Removed From Channel Center Frequency	Minimum Attenuation
between 50 to 100% of	25 dB
between 100 to 250%	35 dB
greater than 250%	Min[43+TPO,80] dB

where TPO = Transmitter Power Output (in dBw)

Wideband

Within Highway Service Channels

Given the affinity between Highway Radio Service users and FHA and the obvious relevance of IVSAWS to Highway Service users, the users of Highway Service channels may be more willing than other mobile radio users to tolerate some interference to their existing narrowband service to accommodate a wideband IVSAWS service. Thus, the question is whether there is a wide enough segment of contiguous Highway Service channels. At low VHF

19 In general the FCC Private Land Mobile rules (Part 90) impose no adjacent channel restriction. However, on adjacent High VHF channels,which are spaced 15 kHz apart (in contrast to the 20+ kHz spacing used in the other bands), base stations cannot be closer than 16 km to each other [section 90.173 (f 11) .

there is a band of 400 kHz from 47.02-47.40 MHz.[20] There is even less bandwidth at high VHF. Ignoring the three police channels that are interspersed in each segment there are two segments of 210 and 220 kHz As discussed above, all of the UHF Highway channels are shared with other services and there are Local Government channels between each channel available to the Highway Service. Thus, a broadband UHF system that only affects the Highway Service is impossible.

Within the Private Land Mobile Bands Below 800 MHz

A wideband IVSAWS system that lay underneath Non-Highway Service channels would need to be more protective of these existing services. Preliminary calculations suggest that at any acceptable interference level, the power/Hz is so low that even with a 10 MHz bandwidth, the allowed EIRP is far too low even to meet the requirements of the fixed permanent sites.

> The calculations are based on the optimistic assumption that an IVSAWS system would be allowed at 30 meters to exceed the threshold of interference of a typical land mobile radio by 20 dB. The resulting EIRP is then compared to the power required for fixed permanent sites (1 W at 900 MHz, l/f2 scaling).

Band	Threshold Sig	IF BW Assumed	EIRP in 10 MHz	Req EIRP	Delta
Low VHF			3uw	2.5 mW	-29 dB
Hi VHF	4 17.5 uV/m	10 kHz	64uw	30 mW	-27 dB
UHF	7 uV/m	10 kHz	147 uw	250 mW	-32 dB

<u>Television Bandy</u> (Low VHF: 54-88 MHz
High VHF: 174-216 MHz
UHF: 470-608 MHz
614-806 MHz)

Narrowband

As with use of the AM broadcast band, there is no single TV channel that would be available on a nationwide basis, nor even on a state-wide basis in most states. The aeronautical marker beacons, land mobile stations, and the adjacency to TV channels 4 and 5 also rules out the use of 72-76 MHz

Wideband

Even with a very optimistic assumption as to the interference IVSAWS would be allowed to cause to TV reception, the total possible power is far too low. Allowable UHF power would be less than 10 uW.[21] The powers in the VHF bands are below a uW.

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20 Assuming that the half the bandwidth to the adjacent channels (47.00 and 47.42 MHz) is useable.

21 17 uW, if the system could operate on both sides of 608-614 MHz (TV channel 37 which is reserved for radio astronomy).

The calculations assume that IVSAWS would be allowed at 30 meters to have a field strength 40 dB below a Grade B signal. Assuming a receiver bandwidth of 4 MHz, this then defined an energy density, which was totaled over the entire bandwidth.

FM Radio Broadcast (88-108 MHz)

[I don't understand what was meant by "FM single sideband transmission" so I have just gone ahead and done the standard analysis. Let me know if something more sophisticated needs to be dealt with.1

Narrowband

As with the other broadcast bands, no single channel is available on a nationwide basis, nor in many states.

Broadband

Again making very optimistic assumptions about how much interference IVSAWS would be allowed to cause, the total allowed power is below 5 uW.

In FCC rule 73.215(a)(l&2), the 0.5 mV/m contour of a class B station must be protected by 20 dB. Optimistically, assuming that IVSAWS would be allowed to have this strong an interfering signal 30 meters from the IVSAWS transmitter and an FM receiver IF bandwidth of 100 kHz, lead to the conclusion that the maximum IVSAWS power in 100 kHz is 75 nW.

410-430 MHz

With the possible exception of 420-422 MHz, this is not a promising band because of the existing users to whom this band has been allocated

410-420 MHz

This band is allocated to government fixed and mobile (generally civilian agencies). Even with a wideband signal, the near/far problem will prevent use.

420-430 MHz (Especially 420-422 MHz)

This band is allocated for high power government radars,[22] amateur use, and certain sub-bands for civilian land mobile in three US cities (Detroit, Cleveland, and Buffalo). Any one of these uses would probably prevent use by IVSAWS. In addition, there may be some additional problems near the Canadian border.

There is however, one exception, the band 420-421 MHz (or possibly 421-422 MHz). In the FCC's Second NOT on preparations for WARC-92, the FCC proposed to reallocate 420-

22 A few (but not all) of the locations where radars in this band operate are listed in US Footnote 228 to the US Table of Frequency Allocations.

421 MHz to Mobile Satellite (space to earth) for use by satellites in Low Earth Orbit (LEO).23 Presumably the plan is that the Government radars can operate. without this I MHz at band edge. If 420-421 MHz is reallocated at WARC-92 to LEO use, then it may still be possible to use 421-422 MHz (under the same general theory).24 It is likely that in the immediate vicinity of the government radars, IVSAWS would be unusable because of interference from the radars Careful study would need to be made to define this interference and determine whether it was acceptable.25

[I leave it to you whether you want to leave any of the following material in.]

UHF Satellite Uplink Transmissions (335.4-399.9 MHz)

(225-400 is a NATO-wide military band. In general DOD does not want anyone else (except aeronautical glide slope) in this band. If you are sure that DOD has (and is planning to have) nothing but uplinks in 335.4-399.9 MHz then it may be worth pursuing.]

LEO Satelite VHF/UHF Frequencies

The prospective LEO (Low Earth Orbit) satellite operators think they can share on a co-primary basis the following bands:

137-138 MHz	downlink
148-149.9 MHz	uplink
400.15401 MHz	either up or down
420-421 MHz	uplink, but the FCC proposed it as a downlink
930-931 MHz	downlink, but the FCC proposed it as an uplink
173.4-174 MHz	uplink

A significant part of their argument in favor of sharing is the intermittent nature of transmissions from the below 1 GHz LEOs. While the probability of having an IVSAWS transmitter in the vicinity of an existing service in these bands is low, once it is in the neighborhood, I assume the non-mobile stations will be transmitting almost continuously. The second problem is that the LEOs are already pushing for these frequencies in the WARC-92 proceeding. Its unlikely that there would still be room for IVSAWS if they get access to these bands,)

23 Second NOTICE in Docket 89-554, supra, at para. 82-83. Note that in footnote 48, the Second Notice records the opposition of the Executive Branch to this proposal.

24 Frequencies above 422 MHz could not be universally used in the US because,under the provisions of section 90.273 of the FCC Rules, radio channels from 422.1875 to 429.975 MHz are available in certain US cities close to the Canadian border.

25 Given the problems of operating a spread spectrum IVSAWS adjacent to high power radars, it is unlikely that a narrowband IVSAWS would work in this band.

A.6. UNLICENSED OPERATION (PART 15)

Devices operating under Part 15 of the FCC Rules do not require any license for their operation. All that is required is an equipment authorization establishing that the device meets the applicable requirements. This freedom from licensing is matched, however, with several disadvantages. Since Part 15 operations are unlicensed, they are not considered in the US Table of Allocations and have none of the protections accorded a licensed service. In particular they must accept any and all interference received from licensed operations, from ISM (Industrial, Scientific, and Medical) operations Pan 18 of the FCC rules, and from other Part 15 operation. In general, the higher power Pan 15 devices are usually allowed to operate only in bands that are already subject to substantial interference. Thus, whether IVSAWS could operate, with sufficient assurance of reliability, under any provision of Part 15 needs to be carefully reviewed.

There are two separate meanings to the term "unlicensed" operation and they need to be distinguished. The most important meaning is that Part 15 use is not established in the US Table of Frequency Allocation and is therefore "unprotected" as discussed above. The second meaning is that paper licenses are not required. While avoiding a requirement for individual paper licenses for every governmental entity with IVSAWS transmitters[26] is clearly important, this objective can be achieved without having to give up the advantages of being a protected service in the US Table of Frequency Allocations.

Since the FCC does not want to have the burden of processing and issuing individual licenses for IVSAWS (let alone IVHS), they will want to exploit any freedom they have to avoid the necessity for a large number of licenses. In 1982 Congress amended Section 307 of the Communications Act to allow "the Commission . . . by rule [to] authorize the operation of radio stations without individual licenses in the radio control service and the citizens band radio service."[27] Since the law goes on to define "the terms 'radio control service' and 'citizens band radio service' [as having] the meanings given them by the Commission by rule," the FCC has considerable discretion to include IVSAWS within this exemption from the necessity to issue individual licenses.[28]

Even if the FCC were disinclined to fit IVSAWS under the rubric of subsection 307(e), there are other options available to the FCC to eliminate the need for individual licenses. For example, the Commission could issue a blanket license to each State government for all IVSAWS activity within that state. The bottom line, is that one does not have to accept the significant disadvantages of Pan 15--the absence of any allocational protection--to eliminate the paper work burden of multiple individual licenses.

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26 Even worse would be the need to issue paper licenses to every motor vehicle owner if IVSAWS was expanded to have a two-way capability.

27 Subsection (e) of 47 U.S.C 307 was added by Public Law 97-259, 96 Stat.1087, 1093, Sept. 13, 1982. The quotation is from paragraph (1) of that subsection. Part 15 authorizations are issued under 47 U.S.C. 302.

28 47 U.S.C. 307(e) (3).

Other than Provisions for Spread Spectrum

The highest power allowed any Part 15 communications device (that is not operating under the provisions of rule 15.247 for spread spectrum) is 18 mW EIRP at 24 GHz.[29] At 902 928 MHz the allowed EIRP is at most 750 uW. Below 902 MHz the allowed powers arc even lower. Thus, no further consideration was given to any section of Part 15 other than 15.247.

Approximate EIRPs, assuming far field relationship and ignoring reflected contribution:

Band		EIRP
13.553-13.567	MHz	3mW
29.96-27.28	MHz	3ouw
49.82-49.90	MHz	3ouw

Spread Spectrum Provisions (FCC Rule 15.247)

Rule 15.237 allows spread spectrum operation in the following three bands with substantial powers:

902-928	MHz
2400-2483.5	MHz
5725-5850	MHz

The maximum allowed EIRP is 4 Watts, with a further restriction of 1 Watt transmitter power output. Both frequency hopping, direct sequence, and certain hybrid systems are allowed. Thus, if we can ignore interference considerations, Part 15 operation under FCC rule 15.247 should meet the requirements for fixed permanent sites.

Excluding self interference between IVSAWS units, there are at least 5 types of interferers that must be considered with respect to these three bands. These are:

- Licensed Government Operations
- Licensed Non-Government Operations
- ISM
- Other Part 15 spread spectrum devices
- Other Part 15 devices (non-spread spectrum)

They are each discussed below. It is worth noting, however, that the only reason spread spectrum Part 15 devices were allowed to operate with such high powers was that these bands were already subject to significant interference.

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29 Field Disturbance Sensors ("radars") under Rule 15.245 are allowed an EIRP of 1.8 W at 10.5 and 24 GHz, but, by definition, their signal cannot carry any information.

Licensed Government Operations

A one page description of Government usage in the band 902-928 MHz was issued by NTIA on October 21,1987. The most notable systems are military radars with a peak power of 66-85 dBm and antenna transmit gains of from 28-37 dBi. While, historically, there was significant use of this band for fixed, point-to-point microwave in the Western US, this usage appears to be phasing out.

With respect to the other two bands, less information is immediately availabIe. In the band 2400-2450, military radars are primary, while in 2450-2483.5 MHz, government radars are secondary to non-government operations. In the band 5725-5850 MHz, military radars are also primary.

Non-Government Licensed Operations

Amateur

All three bands are available for amateur operations, except for the sub-band 2450-2483.5 MHz. With a few exceptions, transmitter powers up to 1.5 kW are allowed. With respect to the 903-928 MHz amateur band, it appears that this band is gaining in popularity (and equipment availability). Thus, the current level of usage is not indicative of how much interference IVSAWS would receive if it operated in this band. Further the FCC has recently removed some of the restrictions that were imposed on amateur operations in this band in Colorado and Wyoming.

AVM

FCC Rule 90.239 authorizes the operation of Automatic Vehicle Monitoring (AVM) Systems in sub-bands of 902-928 MHz. AVMs are authorized under Footnote US 218 to the US Table of Allocations. The rules do not provide any criteria for protection of existing service, nor is there any procedure in the licensing process. Thus, even if IVSAWS were to be licensed in this service, it would be difficult IO obtain sufficient protection from the existing AVM systems, Iet alone if IVSAWS had no protection as a Part 15 operation.

ISM

Industrial, Scientific, and Medical (ISM) Equipment is authorized under Part 18 to operate in ISM bands. Uses include microwave ovens, industrial heaters, diathermy machines, etc. While there are some restrictions on consumer electronics ISM equipment, in general there are no restrictions on how strong the emissions inside an ISM band can be from industrial and laboratory equipment. This wouid be a serious problem for IVSAWS, since all three of the Part 15 spread spectrum bands are also ISM bands.[30]

Other Part 15 spread spectrum devices

While the FCC rules clearly allow IVSAWS operation of a spread spectrum Part 15, they also allow operation by anyone eIse with the same powers and there would be no requirement

30 In fact,their status as ISM bands, which significantly limits their usefulness for most licensed operation, are why spread spectrum Part 15 operations were allowed with such high powers (for Part 15).

under the rules to protect IVSAWS if it operated under Part 15. Thus, an IVSAWS receiver could be located at some distance from its intended transmitter, but relatively close to another Part 15 spread spectrum device. While the spread spectrum nature of the system would tend to protect the communications, this would probably not be adequate.

Other Part 15 devices (non-spread spectrum)

Other Part 15 devices are allowed to use these bands, While, none of them are allowed as much power, the near-far problem would still be present. Given the large number of Part 15 devices that will ultimately be built for these bands, this would be a very serious problem.

Conclusion

Given all of these problems with Part 15, even operating under the liberal (for Part 15) provisions for spread spectrum devices would not be satisfactory for a complete IVSAWS. However, this band may be promising for initial implementations, since much of the equipment discussed above have yet to be heavily produced.

1. Abstract. The purpose of this ENB entry is to present the analysis and results for IVSAWS Task C, Subtask 1, Communication Path Geometry Analysis. As described in the IVSAWS workplan, the geomeuy of communication paths for four significant signing and hazardous roadway situations be identified, including as applicable, those situations identified in Task B, Subtask 3, CARDfile Data Analysis. In this context, "significant" means those situations with geomeuies which will make communication most difficult, such as through dense foliage or over a large obstacle. As applicable, geomeuy will be analyzed for transmitters placed on fixed-permanent, mobile and temporarily-deployed platforms.

2. Inputs. The primary input to this subtask is the Task B Preliminary Report prepared by the University of Michigan Transportation Research Institute under subconuact to Hughes as part the IVSAWS contract The report identifies twelve traffic scenarios which have proved to be hazardous and have remained hazardous despite application of traditional crash reduction treatments. For each scenario, a case study is provided Other documents used as rederences for this subtask are listed in paragraph 7 of this ENB. Information from the literature will be supplemented with empirical data, primarily those parameters not identified in the texts which affect communication path geometries.

3. Processing. Firstly, those key parameters which shape communication paths will be identified and their relevance to IVSAWS communication paths will be analyzed. Secondly, candidate IVSAWS-applicable situations will be identified and analyzed in order to bound the parameters. The situations will be selected such that the identified parameters will be set to a value or condition which will stess the communication link. Where possible, the case study geometries identified in .the Task B report will be utilized However, if it appears that none of case studies provided will adequately bound a particular parameter a hypothetical situation will be substituted.

4. Outputs. The bounded parameters and hypothetical situations will be incorporated into the development of a set of four road geometries with corresponding terrain information. The road geometries and surrounding terrain will be selected such that each key parameter will be set to its "worst case" condition (relative to the IVSAWS application) in one or more of the geometries. The goal is to identify a set of highway/terrain architectures which will stress the communication link between the transmitter and in-vehicle receiver such that upper bounds on the required transmitter power, receiver processing gain, etc. can be evaluated For each geometry, a real-world example of a highway/terrain geometry which approximates the hypothetical case will be identified. The approximations and bounded parameters will serve as inputs to the computer modelling effort (Task C, Subrask 6) which will estimate total propagation loss and probability of communication statistics.

5. Analysis.

5.1 Communication Path Loss Models.

5.1.1 Free-space Path Loss Model. With respect to the IVSAWS communication link, the communication path geometry will affect the path loss between the transmitter and receiver. Path loss is part of the range equation which relates received power (P_r) to transmitted power (P_t) as[1]

$$P_r = P_t G_r G_t \lambda^2/(4\pi R)^2 \qquad (1)$$

where R is the transmission range, λ is the free-space wavelength, and G_r and G_t are the receiver and transmitter gains (losses), respectively, including antenna gains and coupling losses. This equation can be converted to the form[2]

$$P_r = P_{amp} L_t L_a L_f g_t g_r \qquad (2)$$

where P_{amp} is the carrier power at the amplifier output, L_t is the antenna coupling loss at the transmitter, L_a is channel loss due to atmosphere (e.g. absorption, rainfall), L_f is the free space propagation loss, and g_t and g_r are the transmitter and receiver antenna gains, respectively. L_f can be evaluated using the equation[3]

$$L_f(\mathrm{dB}) = 32.5 + 20 \log_{10}(f) + 20 \log_{10}(R) \qquad (3)$$

where f is the frequency in megahertz and R is the range in kilometers. Equation (3) is based upon the free space propagation model which assumes a straight-line communication path between the transmitter and receiver in vacuum. This model is inappropriate for use when simulating the rural mobile-communication environment since the ground, trees and other obstacles will modify or attenuate the communication path.

5.1.2 Free-space Okumura Model. In addition to the free-space model, Sklar, et al[4] have researched four other communication path-loss models, two of which, the Free-space Okumura and Longley-Rice, are applicable to the IVSAWS study. Okumura carried out propagation tests in the VHF and UHF frequency bands for a wide variety of natural terrain and environmental clutter. The experimental data led to a set of charts for predicting propagation loss above free-space loss (L_o). The charts were curve-fit in order to develop an empirical expression for Lo:

$$L_o(dB) = 37.10 + 6.16 \log_{10}(f) - 13.82 \log_{10}(H_R) - a(H_T) + (24.9 - 6.55 \log_{10}H_R)\log_{10}(R) \quad (4)$$

The equation identifies two additional parameters which are affect the communication path geometry, H_T and H_R, the height of the transmit and receive antennas above ground level.

5.1.3 Longley-Rice Model. The Longley-Rice model was designed to predict mean values of path attenuation relative to the free-space loss. It is particularly useful in predicting link propagation losses over long-range irregular terrain for which for knife-edge diffraction losses are significant. The irregular contours and diffractions are characteristic of hilly and mountainous environments in which the IVSAWS will have to operate. In addition to the parameters previously identified in 5.1.1 and 5.1.2, inputs to the model include terrain descriptions (contour and foliage).

5.2 Parameter Identification. The following is a list of parameters which affect point-to-point (transmitter output to receiver input) communication connectivity:

- Carrier power at the amplifier output
- Antenna coupling loss at the transmitter
- Carrier frequency
- Transmission range
- Channel loss due to atmospheric effects
- Transmitter and receiver antenna gains
- Transmitter and receiver antenna heights above ground level
- Surface reflectivity
- Contour
- Foliage

Surface reflectivity, not mentioned in the models described above, has a major impact on connectivity and has been added to the list. Not all of the above parameters are a function of communication path geometry. Carrier power, antenna coupling loss, and carrier frequency are independent of link geometries and will not be examined in the subsequent parameter analysis.

5.3 Parameter Analysis

5.3.1 Transmission Range. Empirically, the required transmission range will be maximum when the closing rate between the hazard transmitter and in-vehicle receiver is greatest Such a scenario would involve a transmitter-quipped vehicle and receiver-equipped vehicle travelling in opposite directions on a highway which supports high-speed transportation. A worst-case example could involve a police vehicle travclling at about 200 kph (120 mph), in pursuit of a threat in front of it, and approaching a large vehicle (e.g. commercial long-haul-truck) with a long stopping distance which itself is travelling at high velocity, for example 130 kph (80 mph) on a slick highway. The closing rate between the transmitter and receiver would be 330 kph (200 mph). In this context, a successful hazard avoidance maneuver would result in the truck moving to the side of the road and stopping before the threat reaches it. Here, it is assumed the threat is 400 meters in front of the police vehicle. It is also assumed that the IVSAWS transmitters will be repeating the "get the heck out of the way" message at least once a second. The SHAWS report[5] shows that the hazard avoidance maneuver is a multi-step process. This process is illustrated in Figure 1 and described below:.

a) The transmitter must send the message IO the receiver. Here, it could take up to a second if the truck was out of communication range just prior to the last transmission.

b) The receiver must generate a warning message for the truck driver. Worst case, the warning would be an audible message of the form, "Emergency vehicle approaching. Please pull the side of the road and stop". A message of this type could take 5 seconds to synthesize.

c) The driver must recognize the warning. The SHAWS report indicates recognition could take up to 2 seconds.

d) The driver must decide upon a warning action and initiate a hazard avoidance maneuver. The time required to perform this step is difficult to bound and is largely dependent upon the driver's interpretation of the urgency attached to the hazard warning. The driver may initiate the maneuver without any external confirmation of the hazard. However, the driver may seek visual or aural confirmation of the hazard before slowing. If SO, and if due to an obstacle or turn in the road confirmation arrives at a truck-to-threat separation which is less than the Decision Sight Distance required IO avoid the hazard, the maneuver will be unsuccessful.[1] Presupposing that the driver initiates a successful response based upon the IVSAWS warning (whether or not the threat is visually detectable) upper bound estimates of the decision-initiation time arc between 7 and 8 seconds.

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1 The Decision Sight Distance is the distance required in order IO perform a hazard avoidance maneuver when visual notification is the only means of threat detection.

STEP	TIME	VEHICLE ACTIONS	DRIVER ACTIONS	IVSAWS RECEIVER	HUMAN FACTORS
1	t0	Vehicle approaches hazard	Driver uses normal driving skills	No Action - signal not yet detected	WARNING EFFECTIVENESS PERIOD
2	t0			Signal is detected, analyzed and warning selected	
3	t1			Warning is generated by visual and/or aural synthesizers	
4	t2		Driver detects warning signal		ADVANCED WARNING TIME
5	t3		Driver recognizes warning		
6	t4		Driver decides warning action		
7	t5		Driver begins warning response		
8	t6	Vehicle is in line-of-sight of hazard			DECISION SIGHT DISTANCE TIME
9	t7		Driver detects hazard		
10	t8		Driver recognizes hazard		
11	t9		Driver decides on hazard avoidance response		
12	t10		Driver begins hazard avoidance response		
13	t11	Vehicle avoids hazard	Driver continues normal driving		

<u>Scenario</u>: Driver is driving, using normal driving skills, and is unknowingly approaching a hazard. The hazard may be unseen and, even assuming ideal driving conditions, is situated such that there is insufficient decision-sight distance to avoid emergency maneuvers and/or accident.

Figure 1. Generalized Hazard Avoidance Time Line Using IVSAWS[6].

e) The maneuver must complete. Similar to step (d), the time (distance) to complete the maneuver is dependent upon driver judgement Given advance warning, the driver should not initiate a panic maneuver. That is, the stopping distance will greater than the minimum. On a slick highway the driver might apply especially light brake pedal pressure in order to avoid a potential skid For this report the stopping distance has been assigned an upper bound of 800 meters. This estimate will be changed if reports ordered relevant to heavy truck braking performance warrant such a modification. The former analysis and Equation 5, below, yield an upper bound transmission range (R) of 2.7 kilometers (1.7 miles).

R=	1 second	[step (a)]	(5)
	5 seconds	[step (b)]	
	2 seconds	[step (c)]	
+	8 seconds	[step (d)]	

16 seconds x 92 ,eters/sec closing rate = 1500 meters

800 meters [step (e)]

\+ 400 meters [threat-transmitter Separation]

2700 meters

The transmission range is largely a linear function of the transmitter-receiver closing rate. Thus, the required uansmission range for permanent fixed-sire and temporarily-deployed transmitters will be considerably less since the velocity of these platforms is zero. Using assumptions similar to those above, the required ranges for fixed and temporary transmitters are both 1.4 kilometers (0.9 mile).

5.3.2 <u>Channel Loss Due to Atmospheric Effects.</u> With respect to the IVSAWS application, atmospheric effects are negligible. The frequency band utilized by the IVSAWS will be under 2.5 GHz. Atmospheric effects are insignificant at frequencies below 3 GHz. For example, at 3 GHz rain falling at a rate of 100 millimeters per hour (4 inches per hour) will cause 0.04 dB/km excess path attenuation. Thus, channel losses due to atmospheric effects will be ignored.

5.3.3 Tr<u>ansmitter and receiver</u> antenna gains.The communication path geometry will affect the transmitter and receiver antenna gains achieved. Communication will be most difficult if the receiving and transmitting antenna beam patterns are tightly focused and the beams point in directions which are perpendicular to each other. However, this extreme case will not be encountered in an IVSAWS application since the in-vehicle receiver will utilize an moni-directional antenna in order to provide 360o coverage Transmitters located at fixed-permanent locations might utilize directional antennas. However, "beam pointing" losses can be ignored since the topography is known in advance and stationary: If necessary, the transmit beam pattern can be shaped to fit the required communication path geometry. In fixed-transmitter scenarios where a single transmitter can not provide adequate coverage multiple transmitters or repeaters can be used. Conversely, antennas mounted on temporarily-deployed transmitters should be omni-directional; in some deployments an omni pattern will be desirable and the deployable transmitters must be able to cover this general case; omni-directional antennas are also more compact and rugged (e.g. short dipole "rubber duckie" antenna) than directional antennas and are therefore well suited to the abuse temporarily-deployed transmitters must endure. Similarly, mobile transmitters are likely to use some form of dipole in order to provide omni-directional coverage when necessary. Thus, with respect to communication path geometry and IVSAWS-relevant antenna directionality characteristics, worst case will involve an "omni-to-omni" link at a high elevation angle (see Figure 2, below).

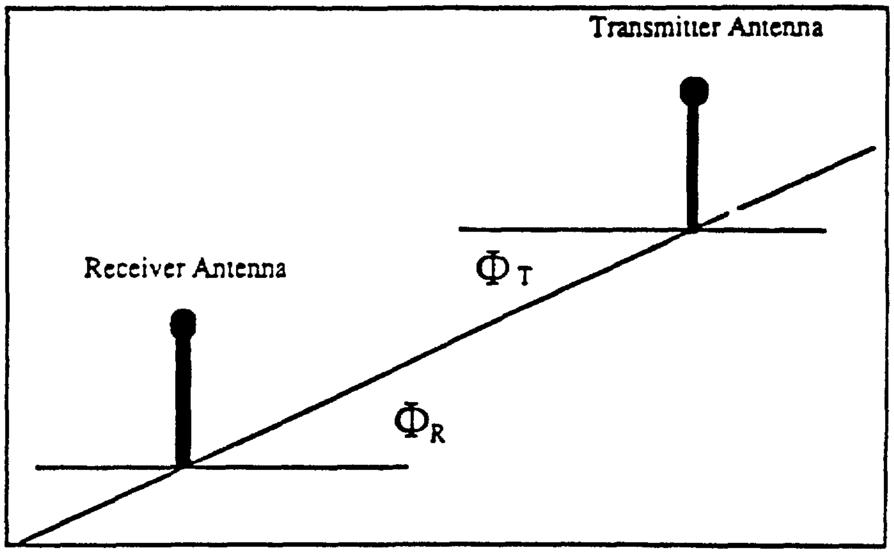


Figure 2. Two-Dimensional Transmitter and Receiver Antenna Elevation Angles.

For example, if the transmitter and receiver where located on different legs of a switchback highway, the angles ϕ_T and ϕ_R might, worst case, approach 60 degrees. In this case, and assuming short dipoles (length << λ; g = 1.5) are used at both receiver and transmitter, the effective gains of the antennas will each be reduced to .38 by the equation[7]

$$\text{Effective gain} = g \cos^2 \phi \tag{6}$$

This can be modelled by assuming a flat road condition and inserting an additional 12 dB worth of path loss. However, on steep and curved highways the maximum closing rate between the receiver and transmitter, and thus the required transmission range, will be less than that on a flat high-speed roadway. Empirically, closing rates should not exceed 190 kph (120 mph). The required transmission range (2.0 lan using Equation 5) will be further reduced due to geometry: The communication path between the transmitter and receiver will still be a straight line yet the length of highway that the vehicles must travel until they meet will be considerably longer. A precursory examination indicates that in order to provide warning at a receiver-to transmitter separation of 2.0 kilometers, the required communication range will not exceed 1.0 km. An examination of topographical maps covering three well-travclled highways with corresponding steep communication elevation angles will be used to confirm this initial estimate and be incorporated into the first revision of this ENB. Thus, due to reduced vehicle speeds and the geometry of mountainous highways, the free-space path loss will be reduced by 10 dB (using Equations 4 and 5). Again, this can be modelled by assuming a flat road condition and subtracting 10 dB worth of path loss. Thus, worst case, a maximum net loss of 2 dB will be incurred due to communication path geometries with steep antenna elevation angles. In short, as long as mobile transmitters and IVSAWS receivers utilize low-gain antennas with wide half-power beamwidths, losses incurred by the geometry of the antenna beam patterns will be largely offset by a decrease in propagation loss due to a decrease in the required transmission range. As the elevation angles decrease, path loss due to increasing required transmission range will grow, but the effective transmitter and receiver antenna gains will increase more rapidly. Net communication degradation in environments with large elevation separations between tne transmitter and receiver should be less than 2 dB.

5.5.4 Transmitter and receiver antenna heights above mound level. According to Equation 4, transmission losses due to antenna height will be maximum when the antenna is closest to the ground. Paragraphs 5.3.4.1 through 5.3.4.4 estimate the minimum antenna heights for each of the IVSAWS platforms. The minimum estimates will serve as inputs to the computer Modelling task which, as described in Paragraph 4, will compute the excess mean path loss as a function of antenna height.

5.3.4.1 IVSAWS-equipped vehicles Ideally, in-vehicle receivers should have their antennas mounted at the roofline. However, due to cost and aesthetic considerations this may not be desirable: Most vehicles come quipped with a long dipole antenna (AM/PM) located at the hoodline and utilization of this asset must considered. The height of this antenna is seldom less than 1 meter. Thus, HR will be set to 1.0 meter when modelling the effects of receiver antenna height (Task C, Subtask 6, Computer Modelling).

5.3.4.2 Deployable transmitters. In most situations transmitters deployed from emergency or maintenance vehicles will sit on the ground. An antenna extension (boom) of some type will be needed in order to avoid excessive losses. At a minimum, a 1.5 meter boom should be stonblc in the trunk of an emergency vehicle (assuming the transmitter, boom, and antenna could be stored as separate assemblies). Thus, HT will be set to 1.5 meters when modelling the effects of deployable transmitter antenna height

5.3.4.3 Mobile transmitters. Unlike passtngcrvehicles, aesthetic concerns are not a major issue for emergency vehicles, buses, farm vehicles, etc.. Mounting an antenna at the roofline is desirable in order to minimize losses. Of the vehicles which are candidates for mobile transmitter installation, police cars and other modified passenger vehicles have the lowest rooflines; approximately 1.5 meters. Thus, HT will be set to I.5 meters when modelling the effects of mobile transmitter antenna height

5.3.4.4 Fixed transmitters. At fixed transmitter sites (e.g. hazardous turn railroad crossing, icy bridge) it will be possible to elevate the antenna In most situations a sign post, bridge testle or other fixed object will be available on which to mount the antenna If not, a pole can be sunk to provide adequate elevation. In any case, it should be possible to elevate the antenna at least 4 meters. Thus, HT will be set to 4.0 meters when modelling the effects of fixed transmitter antenna height

5.3.5 Surface reflectivity. In the IVSAWS environment radio waves will reflect off of many sources including hills, roads, aircraft and buildings. The primary effect of the reflections will be to introduce multipath fading. The multipath fading will be worst when a reflected signal and the desired signal arrive at the receiver 180o out of phase and destructively interfere with each other. If the amplitude of the reflected and desired signal are nearly equal, a deep fade will occur and communication will be effectively blocked. This type of multipath fading is called Rayleigh fading and is “far and away the most difficult challenge of the mobile (radio) environment [8]". The effect of multipath fading is most pronounced in environments with a large number of reflectors (e.g. city street with tall buildings). Yet even in the rural environment, aircraft, road surfaces, canyon walls and signs will produce numerous and significant fades. At frequencies above 100 MHz, that maximum fades will occur hundreds of times per second when the receiveing vehicle is travelling at modest speeds. Even in a static environment the location and depth of multipath fades is difficult to predict. objects that seem to be unlikely reflectors will reflect; an apparently insignificant reflection path will bounce off another reflector and become significant The use of omnidirectional transmitter antennas further complicates the problem by increasing the number of possible reflection paths with respect to narrow-beam point-to-point communication. Due to the imprecision and complexity associated with analyzing this problem, the geometry (location) of multipath fades will not be predicted or computer modelled. Rather, it will be assumed that frequent and severe fades will occur in the IVSAWS environment and waveform design(Subtask 4) will be used to minimize the impact of fading on communication performance.

5.3.6 Contour The losses due to non line-of-sight communication over an ideal knife edge can be calculated as a function of frequency, distance from the transmitter to the edge, distance from the receiver to the edge, and height of the edge. However, the mountains, hills, and other obstacles likely to be encountered in an IVSAWS application will diverge considerably from the ideal case. Losses over real-world edges are typically 10 to 20 dB greater than the ideal case[9]. The effects of hills, mountains, and knife-edges with respect to excess mean path loss will be simulated by Hughes' Langley-Rice computer model for at least two IVSAWs-relevant scenarios with such topography

5.3.7 Foliage. In general, foliage will act as an attenuator between the receiver and transmitter. Wooded areas are particularly strong attenuators[10]. The effects of trees with respect to excess mean path loss will be simulated by Hughes' Longley-Rice computer model for at least one IVSAWS-relevant scenario with such topography.

6. Scenario Selection. Based upon the previous parameter analysis, four scenarios have been identified for computer simulation and estimation of total path loss. The scenarios and associated link parameters are summarized in Table I:

Table I. Scenario Selection

Scenario	Parameter Stressed by Scenario
Straight, flat high-speed highway	Communication range
Curved highway through trees	Foliage attenuation. antenna elevation angles
Highway through rolling hills	Diffraction loss due to contour
Curved road with interleaving mountains	Diffraction loss due to contour

For each scenario, three cases will be modelled: mobile transmiter, temporarily-deployed transmitter, and fixed-site transmitte. Thus, the effects of transmitter and receiver antenna heights will be modelled for each IVSAWS deployment option. As mentioned previously, the geometry (location) of multipath fades due to surface reflections will not be modelled.

6.1 Straight, flat high-speed highway scenario (Scenario . Site selection for this scenario is somewhat arbitrary since straight and flat stretches of highway are numerous. Case #6 from the IVSAWS Task B preliminary report was chosen to model this gewmetry (see Figure 3).

The stretch of road involved is U.S. Highway 23 near its intersection with Michigan Highway 14. The parameters for this scenario are listed in Table II.

6.2 Curved highway throuoh trees (Scenario B). U.S. Highway 89 Alternate, approximately 13 miles north of Sedona, Arizona was selected to emulate this **scenario** *(see* Figure 4). At the northern end of Oak Creek Canyon, the highway has sharp curves and covers a significant elevation differential (approximately 700 ft differential in 2 miles). Through this region, posted speed limits drop to 15 mph. Foliage along this route is dominated by dense oak and pine woods. The parameters for this scenario are listed in Table III.

6.3 Highway through rolling hills (Scenario C). U.S. Highway 385, approximately 1 mile south of Hot Springs, South Dakota was selected to emulate this scenario. Figure 5 shows the heights of the hills over which the radio waves must propagate. A topographic map like those shown in Figures 4 and 6 has been ordered and will replace the sketch in a subsequent revision of this ENB The parameters for this scenario are listed in Table IV.

6.4 Curved road with interleaving mountains (Scenario D) Interstate 90, through SnoqualmieU Pass, Washington was selected to emulate this scenario. Figure 6 shows the mountain over which the radio waves must propagate. The parameters for this scenario are listed in Table V

Table II. Scenario A Parameters.

	CASE A-1	CASE A-2	CASE A-3
Transmitter platform	Fixed	Mobile	Deployable
Transmitter antenna gain	15 dB	1.5	1.5
Height of transmitter antenna above ground level	4 meters	1.0 meter	1.5 meters
Length of road between transmitter and receiver	1.5 km	3.0 km	1.5 km
Communication range	1.5 km	3.0 km	1.5 km
Receiver antenna gain	1.5	1.5	1.5
Height of receiver antenna above ground level	1.0 meter	1.10 meter	1.0 meter

Scenario Features: Straight and flat highway (see Figure3). Line-of-sight communication between transmitters and receivers. Communication range is maximized in this scenario

Table III. Scenario B. Parameters.

	CASE B-1	CASE B-2	CASE B-3
Transmitter platform	Fixed	Mobile	Deployable
Transmitter antenna gain	5 dB	1.5	1.5
Height of transmitter antenna above ground level	4 meters	1.0 meter	1.5 meter
Length of road between transmitter and receiver	1.1 km	1.0 km	2.2 km
Communication range	0.6 km	0.6 km	0.4 km
Receiver antenna gain	1.5	1.5	1.5
Height of receiver antenna above ground level	1.0 meter	1.0 meter	1.0 meter
Antenna elevation angles,NT and NR	1E	23E	4E

Scenario Features: Curved highway through dense woods. Significant antenna elevation angle. (see Figure 4).

Table IV. Scenario C Parameters.

	CASE C-1	CASE C-2	CASE C-3
Transmitter platform	Fixed	Mobile	Deployable
Transmitter antenna gain	15 dB	1.5	1.5
Height of transmitter antenna above ground level	4 meters	1.0 meter	1.5 meters
Length of road between transmitter and receiver	0.7 km	1.9 km	1.2 km
Communication range	0.7 km	1.9 km	1.2 km
Receiver antenna gain	1.5	1.5	1.5
Height of receiver antenna above ground level	1.0 meter	1.10 meter	1.0 meter
Height of hill(s) between receiver and transmitter	6 meters	20 meters 26 meters 50 meters	20 meters 26 meters

Scenario Features: Curved highway through dense woods. Significant antenna elevation angle (see Figure 5).

Table V. Scenario D. Parameters.

	CASE D-1	CASE D-2	CASE D-3
Transmitter platform	Fixed	Mobile	Deployable
Transmitter antenna gain	5 dB	1.5	1.5
Height of transmitter antenna above ground level	4 meters	1.0 meter	1.5 meter
Length of road between transmitter and receiver	Not applicable	3.0 km	2.0 km
Communication range	0.8 km	2.0 km	1.7 km
Receiver antenna gain	1.5	1.5	1.5
Height of receiver antenna above ground level	1.0 meter	1.0 meter	1.0 meter
Height of mountain between receiver and transmitter	Line-of-sight	304 meters	152 meters

Scenario Features: Curved highway with interleaving mountains (see Figure 6).

CASE NO.: UM-2613-88
CASE VEH. (A): 1988 DODGE
TYPE: RAM RAIDER, MPV
DRIVER: 18-YRS., MALE
VEH. (B): 1985 FREIGHTLINER SEMI
VEH. (C): 1981 PONTIAC PHOENIX
VEH. (D): 1976 CHEVROLET CAMARO

DATE / TIME: 8-11-88 / 0850HRS.
WEATHER: CLEAR
ROAD SURFACE: DRY
ROAD CONSTRUCTION: CONCRETE

VEH. (E): 1986 BUICK ELECTRA
VEH. (F): 1976 DODGE MOTOR HOME

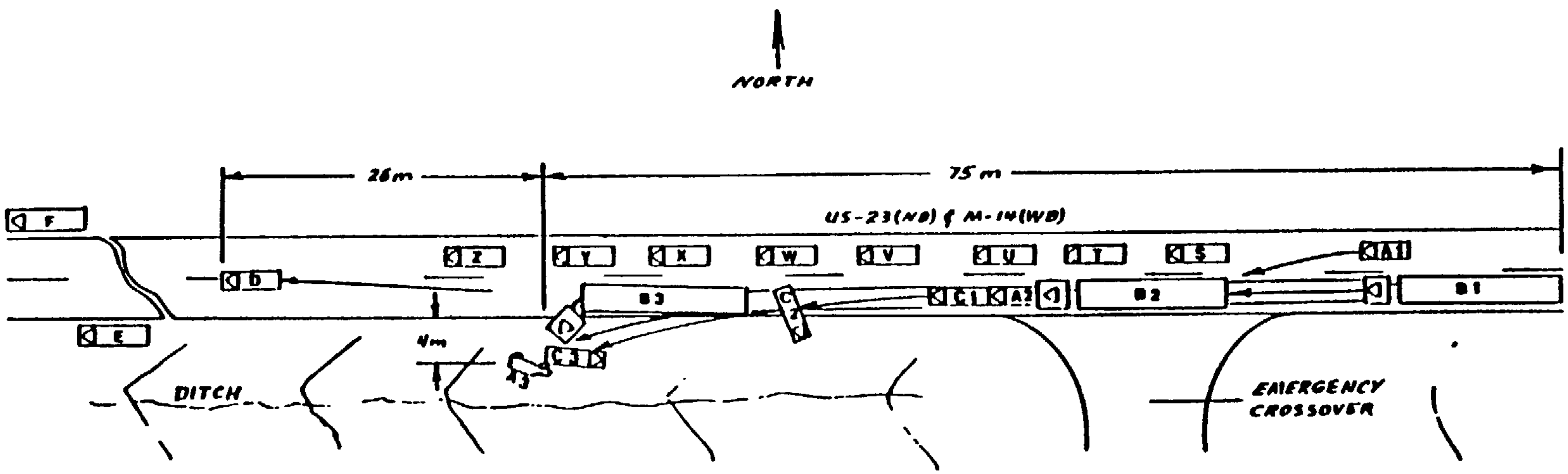
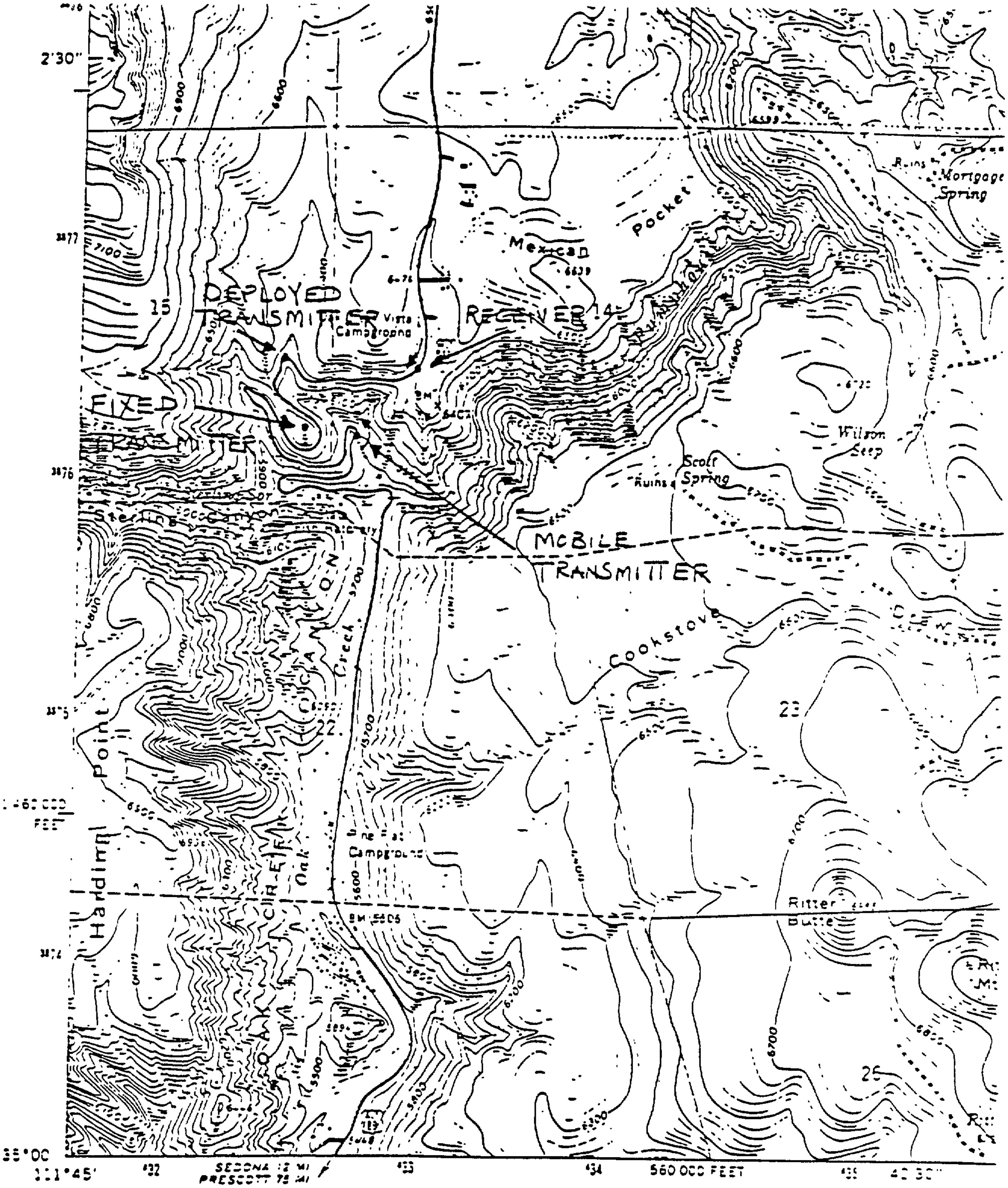


Figure 3. Scenario A - Straight, flat high-speed highway.

[FHWA I-159]



Mapped by the U S Forest Service
Edited and published by the Geological Survey

Control by USGS, NOS/NOAA, and USFS

Topography by photogrammetric methods from aerial photographs taken 1959. Field checked by USGS 1962

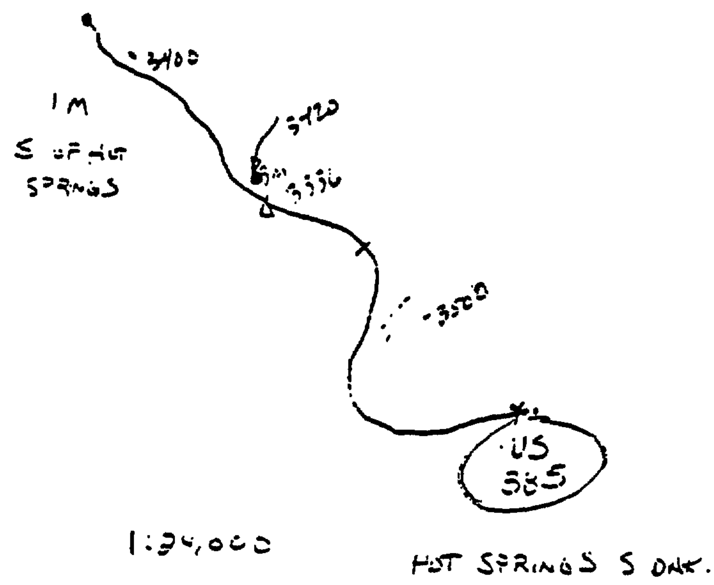
Polyconic projection. 1927 North American datum
10,000-foot grid based on Arizona coordinate system, central zone

1000-meter Universal Transverse Mercator grid ticks zone 12, shown in blue
To place on the predicted North American Datum 1983 move the projection lines 5 meters north and 65 meters east as shown

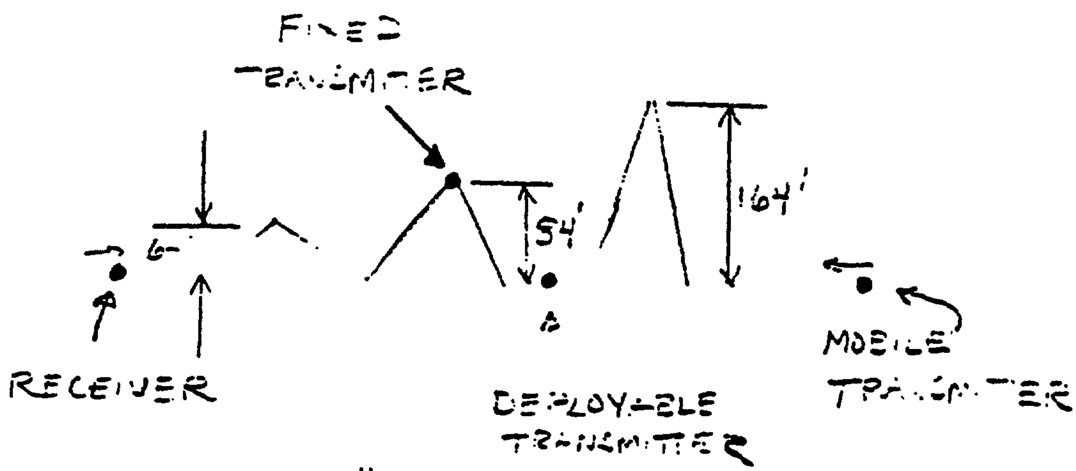
There may be private inh... the National or State rese...

[FHWA I-160]

Figure 4. Scenario B - Curved highway through trees.



"TOP VIEW"



"SIDE VIEW"

FIGURE 5.

Scenario C - Highway through rolling hills. [FHWA I-161]


Kendall Peak Lakes
KITTITAS CO
KING CO
Commonwealth
Snoqualmie Pass
Snoqualmie Pass
Commonwealth Campground
River
Mountain
Denny
SUMMIT
ACRES
MOBILE
Keekwulee Falls
Snowshoe Falls
Hemlock Peak
Mile 28
Lodge Lake

[FHWA I-162]

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